VISUAL SIMULATIONS OF WESTERN SPRUCE BUDWORM DAMAGE IN MIXED CONIFEROUS FORESTS

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OBJECTIVES

1. *Develop a means of quantifying the visual effects of different degrees of insect infestation on forest scenes.*

2. *Develop means of using computer video image capture and "painting" procedures to simulate predicted levels of insect damage.*

3. *Assess the influence on viewer preference of the degree and extent of insect damage visual impacts.*

4. *Investigate the suitability of computer video-imaging as a means of:*
   a. simulating various management options.
   b. simulating the effects of damage on snow scenes.

INTRODUCTION

Mixed conifer forests in Colorado, New Mexico and other areas in the United States have been subject to widespread and highly damaging insect attack. An example is the defoliation of Douglas Fir and White Fir forest species by Western Spruce Budworm. The nature of the damage consists of defoliation of the emerging buds, resulting in complete loss of foliage over a four year period and possible death of the tree. Dying vegetation typically displays a bronze coloration, followed by greying of the appearance as the damage proceeds to death and then loss of small branches etc. Infestations can be small scale and patchy, or can involve many acres of forest resulting in tree mortality approaching 100% through entire mountain watersheds.

The visual impacts of infestations are highly evident at later stages of infestation. With extensive loss of tree limbs etc. the economic impacts can be great, in the direct value of timber sales, in the removal of protection to ski slopes resulting in loss of revenue to resort owners, and in losses attributable to reductions in scenic values.

Treatment can be attempted by annual spraying of biological insecticides, but each treatment is effective for only a single season. Alternatively, silvicultural treatments directed at increasing the heterogeneity of species

and age-class mixes may be effective -- existing homogeneous stands of even-age firs are highly susceptible to insect predators.

Entomological modeling of anticipated impacts under different environmental conditions accompanied by realistic visual modeling of the visual impacts has been identified as a potentially powerful way to inform and mobilize public opinion.

This cooperative study by the Rocky Mountain Forest and Range Experiment Station, and the Universities of Arizona and Illinois addressed the validity and utility of computer video imagery as a suitable communication medium. The goal of the study is to develop consistent and valid techniques for representing different levels of impact in response to a predictive model, and then to use the resulting images in perception studies directed at modeling public preferences based on forest and insect damage variables.

VISUALIZATION OF RESOURCE IMPACTS

Over the past three or four years the science and technology surrounding environmental, geographic and land information systems has grown rapidly. Much of this development has been directed at the predictive modeling of changes to complex resource systems, such as forests, to allow more accurate and more informed decision-making. Significant advances have been made in both the data manipulation and visualization aspects of modeling for use in the public planning and policy arena.

"Levels" of resource planning communication

A range of visualization formats are available to the resource planner. They range from tools for communicating relatively abstract data relationships to resource management experts, to highly realistic simulation tools for detailed public review:

<u>GIS output, 2-D colored map</u>	Scoping. Used by disciplinary experts with good understanding of the underlying data at early, gross, scales of review.

<u>3-D modeled and shaded view</u>	Appraisal, analysis, evaluation. Comparison of alternatives. Detailed internal review by knowledgeable reviewers.
<u>Video simulation</u>	Review, approval, detail evaluation. Public hearings, EISs, public relations, public participation.

Resource modeling and visualization

While the focus of the majority of modeling efforts has been on economic, engineering and biological factors (e.g., PROGNOSIS, CONTAGION, IPIAS, INFORMS), it has been acknowledged that the responses of public groups to changes in forest scenery can significantly influence the implementation of a forest harvest plan. A hindrance in the development of models of scenic attractiveness has been that, while biological, economic and engineering responses of the forest environment can be monitored and assessed within the stand or its immediate surroundings, visual impacts take effect at much greater distances and range well beyond the physical extents of the area covered in a typical harvesting plan.

To date, techniques for modelling visual impacts have been restricted to 2-dimensional representations or realistic artists' impressions. Such images are open to criticisms of bias and inaccuracy and inflexible in responding to "what if" kinds of speculation.

Unfortunately, the ability to present the visual impacts of complex forest plans as high quality realistic images, while acknowledged as critical for effective public review, has been lacking from recent development of technical tools based on Geographic Information Systems and Digital Image Processing.

The development of graphic display tools responsive to quantitative modelling tools would make it possible to visualize the outcomes of numerous alternative development strategies. In contrast to current practice where sophisticated visual displays are only prepared after major

decisions are made, such a tool would make visual review a component of the earliest stages of project development, as well as lending itself to more effective public interaction with the planning process. It is now possible to address some of these shortcomings with computer-based video-simulation.

A further issue in the incorporation of public values into the computer-based evaluation models currently under development is the frequent absence of quantitative data linking subjective responses, such as scenic preference or visitor satisfaction, to management operations. Developing such models is hindered by the difficulty of isolating the influence of a variable such as silvicultural treatment from other issues of topography, vegetative qualities, and location. It is usually impractical or politically undesirable to conduct a controlled experiment which systematically treats a given piece of forest in the numerous ways available to managers. A successful visual simulation tool which can be used as a reliable surrogate for the on-site experience of scenic beauty would be a valuable research tool.

Video-imaging, a combination of computer and video technologies, is a recent development as a microcomputer tool. It offers an inexpensive and easy-to-use tool for making realistic simulations. The basic tools and techniques are described elsewhere (e.g., Orland, 1988; and in press). It offers opportunities for improvements in communication, as well as in environmental perception research. Application of this tool to simulation of insect damage, for public communication as well as research needs, is the focus of this project.

METHOD AND FINDINGS

This project has been carried out in six phases:

1.	Exploratory studies	Evaluate existing video-imaging techniques based on traditional artistic processes.

	Image processing	Exploration and evaluation of rendering procedures based on image processing approach.
2.	Pilot - implementation I	Identify pilot study locations. Select and sample typical scenes. Apply simulation process to scenes.
	Expert evaluation I	Feedback from forest pest management experts on validity of resulting images. Guidance for creating future imagery.
3.	Implementation II	Modification of simulation procedures, re-application to pilot study scenes. Assemble study set of images for perception study. Review results.
	Expert evaluation II	Feedback from FPM experts. Evaluate process and findings from preference studies.
4.	Implementation III	Modify simulation procedures. Up-grade simulation techniques. Perception study. Review results.
5.	Evaluation of tool for other forest impacts	Investigate the suitability of computer video-imaging as a means of simulating: a. various management options. b. the effects of damage on snow scenes.
6.	Review and implications	Appraise progress, identify directions for future work. Prepare five-year plan for development and technology transfer.

1. EXPLORATORY STUDIES

Evaluate existing video-imaging techniques based on traditional artistic processes. Image processing evaluation. Exploration and evaluation of rendering procedures based on image processing approach.

The existence of a tool capable of creating full-color, realistic, simulations of future conditions offered great potential to forest managers and social scientists. Managers saw a means of more clearly representing their planning proposals to the public. Scientists interested in environmental perception issues saw a way to control extraneous variables in the study of subjective responses to the environment.

A pilot study was initiated to investigate the potential for using such techniques to simulate the visual effects of Western Spruce Budworm damage. The investigators were supplied with a series of images illustrating a range of damage scenarios from undamaged to highly damaged. A series of experiments were undertaken to manipulate undamaged scenes to indicate various degrees of damage, and to restore highly damaged scenes to an undamaged appearance.

Images were digitized using a Truevision TARGA16 graphics controller installed in an IBM PC-AT (80286-8MHz, 80287, 512k RAM, 30Mb disk). Images were scanned using a color slide adapter mounted on a video camera. Digitized images were viewed using an NEC MultiSync RGB analog computer monitor.

The standard graphic arts software available for the Truevision TARGA16 color controller were tested for their usefulness as editing tools. The products available in the Imaging Systems Lab included TIPS (AT&T GSL, 1986) and Lumena16 (TimeArts, 1987). At a later stage IMAGE software (New Image, 1988) became available. These products each have numerous graphics tools available including painting, cut-and-paste, and various styles of tinting.

Results

Attempts to simulate insect damage effects met with limited success. Rabin (1989) had good success simulating the effects of limb rust. However, the main technique used in that study was to remove branches from images of trees. Graphically, the process was one of capturing portions of the sky, or other background in the image, and "pasting" them over the areas of limb to be obscured. Some graphic arts expertise is needed to effect these changes successfully, but the software tools for these tasks are quite powerful. As a result, the simulation process used by Rabin to achieve high quality images was fairly straightforward.

Representing the color changes characteristic of insect damage, over broad areas of forest, presented more of a challenge. Landscape scenes represent areas with immense variety of visual characteristics. To recreate these effects using a cutting and pasting technique would demand a comprehensive library of part-images of the desired damage characteristics. Moreover, 2-D raster images such as these hold no information about slope and orientation of surfaces in an image, no data about scale of close or distant trees, no guidance for successful rendering of textures and shadows. Thus there is little in the way of guidelines available to ensure realistic outcomes.

Initially the intention of the study had been to use such "traditional" graphic arts techniques to visually alter the images of forest scenes. However, it quickly became obvious that another approach was necessary.

An important aspect of the successful implementation of these techniques was the necessity to achieve consistency in representing known levels of insect damage. Consistency of color rendering is also an issue in assembling cut-and-paste images. In order to address this problem a set of image processing utilities had been developed at the Imaging Systems Laboratory. These were evaluated for simulating the changes arising from insect damage.

Evaluating a digital image processing approach

The computer software in use, a package initially named "Picture", later "Toolbox" (Gupta and Orland, 1988), was developed at the University of Illinois. The package comprises tools for a variety of color palette manipulations:

a. *Matching the coloration of an image to match a target area defined in a second image,*

b. *Automatically editing areas of unwanted color in an image, as defined by a target area, and*

c. *A "colorize" module that enables the user to specify color changes to pixels within pre-defined ranges of color value.*

"Colorize" was the module identified for use in this study. The tool sums the numbers of pixels corresponding to each different intensity level of Red, Green, and Blue in a defined area and calculates a mean color intensity and standard deviation.

To implement changes in coloration corresponding to insect damage, analyses were made of scenes indicating both damaged and healthy vegetation to quantify the changes in color value corresponding to different levels of insect predation. Experiments were conducted to find whether additive or multiplicative processes were more effective in simulating color changes on unaffected vegetation. Multiplication, which tends to increase contrast in high valued pixels, was found to be more effective.

This experimentation indicated promise for applying digital filtering techniques to ground level images to represent changing levels of infestation. The nature of the patterns of infestation, with damage occurring over large areas, lends itself to simulation by image filtering, offering advantages in realism and time-saving over the manual editing alternative. In insect damage situations the visual changes accompanying damage are largely seen as shifts in coloration, with the textural qualities

of the forest scene remaining somewhat similar, at least at early stages of infestation.

The bigger advantage of such an approach over manual graphic arts techniques lay in the potential for achieving consistency, and in replacing artistic intervention by computer processes for simulation.

However, the "blanket" changes to all pixels in an area resulting from first attempts gave an unconvincing appearance. The issues were a general loss of textural character, especially in altering areas in shadow, and the inclusion of non-fir species which would not be subject to attack. To address these problems a filtering procedure was developed so that the only pixels altered in value were those that corresponded to a predetermined range of values.

For example, by initial analysis of the coloration of fir species a filter could be defined such that only those trees were altered in the filter pass. A combination of one or more passes could fine-tune the coloring process to satisfactory coloration of complex visual arrays.

Analyses of color changes

At this early stage of the project control over image color values, and hence the ability to calibrate images to pre-determined damage levels, was minimal. The technical shortcomings included:

a. Inconsistent original photography. The photographs used in this study were collected as records of insect damage. Little attention was given to achieving high color saturation etc. Lighting conditions varied from low- to high-sun, direction of photo relative to sun varied, and there were varying levels of cloud and haze.

b. Poor image scanning. Scanning via video camera, while adequate for many purposes, introduced numerous sources of variability in color control. Conversion from RGB to Composite Video to RGB (see Orland, 1986, in press), variable gain characteristics of the camera color sensors (Spomer, pers. comm.), and light source for the scanning process are all sources for color variation.

c. Limited range of image processing functions. "Toolbox" was developed in-house to perform specific tasks. At the time of these initial tests there was no filtering function available to control the range of pixel colors manipulated.

In this development phase of the study there was no necessity to conduct extensive evaluations of the images. Nevertheless, in order to understand the nature of changes made to images an image analysis study was undertaken.

Three "good", and three "bad", images were identified. For each a target area of manipulated image was identified. Mean and standard deviation color values for each of the Red, Green, and Blue channels were obtained using "Toolbox" (see Table 1), and the data plotted as line charts using Statview for the Macintosh (Figures 1-9).

The purpose of this analysis was to investigate the nature of changes made in making good images, and the contrasts between good and bad. In all cases the grey component of the manipulated images was indicated by an increase in Green and Red values, Green remaining static. No effect of good vs. bad simulation was noted -- the statistical within-group differences being at least as great as the between-group.

2. PILOT STUDY - IMPLEMENTATION I

Identify pilot study locations. Select and sample typical scenes. Apply simulation process to scenes. Feedback from forest pest management experts on validity of resulting images. Guidance for creating future imagery.

Baseline images for the study were collected in the Red River area near Taos in northern New Mexico. The area consists of steep, dry, valleys with over-mature stands of mixed conifers. Douglas fir (Pseudotsuga), and White fir (Abies), species comprise up to 90% of the tree cover.

In response to concerns arising from the pilot study, guidelines were developed for collecting photographs optimized for capturing into the

digitized video format (Orland, 1988b). Forest scenes were photographed showing a range of healthy forest vistas. An additional set of variously damaged vistas was collected to provide guidance to the image processing processes.

As before, images were video-scanned using a slide attachment on a video camera. In addition, the "Toolbox" software was up-graded to enable the use of a "filter" process for making color change passes. For each of the Red, Green, and Blue color channels an upper and lower value can be set such that image processing functions will only affect pixels within those ranges of values.

Results

The photo guidelines proved to result in consistent high quality images. Unfortunately this is at the expense of flexibility in field operations. The criteria developed for achieving the best images are quite restrictive and may necessitate return visits to sites. Future work should assess these limitations and attempt to relax the requirements while retaining the quality images.

While considerably improved over the results of the pilot study, this second set of simulations revealed that, while some highly effective representations of the characteristic texture of the forest were achieved, the subtle color changes accompanying insect damage were not easily obtained. Some color changes were exceptionally difficult to simulate, notably the bronzing effect of dying vegetation, and frequently took on a "blobby" appearance in the simulation.

At an early stage in development these images were taken to Forest Pest Management experts in the offices of Forest Service Regions 2 and 3 for appraisal, and for guidance in future simulations.

Reviews were generally favorable but again pointed to difficulties with establishing the validity of the simulations. Beyond the technical issue of whether a particular coloration could be achieved reliably, there was the bigger question of matching classes of insect damage to image processing algorithms to ensure reliable representations.

Nevertheless, comprehensive guidelines for image production were developed, and secondary sources of information on visual impacts of insect damage identified.

Graphical analyses of images were not developed at this stage of the study.

3. IMPLEMENTATION II

Modification of simulation procedures, re-application to pilot study scenes. Assemble study set of images for perception study. Review results. Feedback from FPM experts. Evaluate process and findings from preference studies.

In response to criticisms from reviewers, each original image was subjected to a combination of high- and low-pass convolution filters to effect a sharpening of image quality.

On the basis of information derived from the previous review, a full set of study images was developed. For each of the study scenes, five levels of damage were simulated -- two levels of bronzing and three of greying.

A correlational study was conducted to establish the validity of digitized video vs. original color slide photography. Subsequently, study images were viewed by respondent groups to obtain evaluations of their scenic qualities. These studies are reported elsewhere (Daniel and Orland, 1990???).

A further expert evaluation was conducted at the Western Forest Insect Work Conference in 1989. A workshop format was used as a setting within which FPM experts could view and critique simulations.

Results

Initial results of perception studies based on these images were not encouraging. Scenic beauty judgments and expert evaluations of image validity were erratic and inconclusive. The results of the public group and expert evaluations are reported in full elsewhere (Daniel and Orland, 1990???).

A Scenic Beauty Estimation procedure (Daniel and Boster, 1976) was used to estimate public response to changing levels of insect damage. For both bronzing and greying effects there was a linear relationship between increasing damage and reducing scenic beauty judgement. There were generally lower ratings for bronze vs. grey images, although in reality grey represents a greater degree of damage.

Experts responded in a less structured survey format where slides were shown one at a time and detailed criticisms recorded. Analysis of this kind of data is more demanding, but in any event there was much less agreement between experts on specific issues of coloration, and generally strong criticism of the simulated effects of higher levels of damage, both bronze and grey.

These responses were not unanticipated by the investigators. While the first damage level simulations, both bronze and grey, were subtle and quite convincing, attempts to indicate higher levels frequently resulted in images with a "blobby" appearance. Clumps of adjacent, similar-color pixels yielded an unnatural appearance, especially when those pixels indicated high levels of color change. Bronze colors were particularly unnatural looking in these situations, as well as exhibiting more contrast between impact and background than grey coloration.

One source of these difficulties was the use of images scanned using a video camera. While adequate for cut-and-paste simulation the lack of color and spatial resolution in the resulting images rendered the filtering techniques less useful. The technical issues of color and spatial resolution are discussed in more detail elsewhere (e.g., Orland, 1988), but the effect of the video scanning in this instance was: a) to reduce contrast and saturation in the digitized image as compared with the original color slide, and b) to "smooth" variation in the original image because of the low resolution of the video camera. As a result of low differentiation between adjacent pixels, a color change tended to "spread", giving the blobby and blurry effects. This problem may have been exaggerated by the use of the "sharpening" function that sought to improve image contrast and definition.

A more detailed analysis of the pixel values within the images was performed. As reported for the pilot study, three good and three bad simulations were sampled from this phase of the study and an extensive analysis of color values conducted. Results of those analyses appear in Table 2. Graphical presentations of the data appear in Figures 10-18.

Again, the color values followed the expected pattern, increases in Red color component accompanying increasing bronzing, and converging Red, Green, and Blue values accompanying greying. Once again, however, there was no clear difference between the patterns of color values of good and bad images -- within-group variability was at least as great as between-group.

Conclusions

Two major problems were identified in this portion of the study. First, images of low contrast, saturation and definition cannot be processed with sufficient subtlety to simulate the required effects. Second, variations between images made it difficult to develop standard procedures and ranges of digital filter values.

Many of the inconsistencies in captured color values, contributing to the above problems, were felt to be the result of using a video camera as the scanning device. In addition to the accepted losses of contrast and resolution, the gain characteristics of color video components are known to be both non-linear and to vary across the RGB color channels, introducing hard-to-predict variations.

At the time of this portion of the study, digitizing scanners were becoming available at reasonable cost and appeared to offer a more reliable method of image input. Tests were conducted by sending color slides to a service house (ColorSet, San Francisco) for scanning. The images were returned as computer files on floppy disk. Although the advantages of greater image sharpness and better color were evident, control over quality of the resulting images was apparently difficult (e.g., color balance), and the cost was high.

It was suggested that the study be extended to allow the more detailed investigation of the problems identified above. The following steps were proposed:

a. A number of scenes matching those from the original image set would be scanner digitized and qualitative judgments made of image improvements.

b. Scenes from a. would be treated using identical filters to those from the study set. Evaluations would be made of improvements/degradations of image quality.

c. Using information from a. and b. a sub-set of the original study slides would be developed into simulations and used in a further validation and scenic preference study.

4. IMPLEMENTATION III

Up-grade digitization techniques. Modify simulation procedures. Perception study. Review results.

The US Army Construction Engineering Research Laboratory donated the use of digitizing scanner facilities for this stage of the project. The scanner in use was a Howtek, model 35S, which enabled the direct scanning of color slides and could provide images in a number of different formats.

A sub-set of the images from the previous study was digitized. Using the color manipulations developed for the previous images as guidelines, the scanned images were manipulated similarly. Modifications of the image processing methods were made to combat the problems of "blobbiness".

As part of the "filtered multiply" function in Toolbox, it was possible to specify a range of pixel values to be affected by a single filter pass. In this phase of the study, filtering was accomplished in up to three passes, the first addressing a narrow range of values and the second a somewhat wider range, but a smaller change of values. In this way it was hoped to accomplish a more natural-appearing gradation from unaffected to affected areas in the image.

Results

The visual qualities of the resulting images were a considerable improvement over previous sets of images. The improvements were credited to two sources: a) improved image color and spatial resolution, and b) improved image processing.

Examination of the images revealed much greater sharpness in the scanned images. Adjacent pixels displayed greatly different colors, in contrast to the low resolution of video-input images. In some particularly high-contrast snow scenes the effects were most striking -- the scanned image appearing sharper than the color slide original. In fact, the latter high contrast capability of the Howtek scanner may be its biggest disadvantage for these projects.

In a number of instances high contrast originals were nearly impossible to scan successfully, because of the exaggeration of contrast occurring in that process. Extensive analysis of pixel values revealed that the scanned images, while attractive, had excessive areas of shadow and highlight. It was possible to adjust these values using software with the scanner, but it was not possible to re-create data lost within those very dark and light areas. The particular scanner in use appeared to be set to set a rather high "dark" threshold, and a rather low "highlight" threshold. The combination of these effects tends to give images an impression of higher sharpness and sparkle. Unfortunately these are not the qualities sought in making valid and reliable insect damage simulations.

The continuing development of "Toolbox" by Betty Evans, an assistant at the University of Arizona, and the development of a manual (Evans, 1989), further enhanced that tool. Increasing experience with the software, and experimentation by the laboratory assistants, resulted in considerable improvements in image quality in this final phase of the study. The range of damage simulations attempted in the previous phase of the study were repeated.

These images were also subjected to detailed color analysis. Again, three "good" and three "bad" images were analyzed. Data for these images is

shown in Table 3, individual plots of mean color values for the individual images are Figures 19-27. As with the previous analyses the patterns of color value change are consistent with the damage effects and are remarkably consistent across images. Once again though, within-scene variations are as great as between-scene.

Images from this portion of the study accompany this report. The work is very recent and has not received the extensive review of FPM experts as in earlier stages of the study.

Conclusions

Informal reviews arising out of numerous presentations of this work (Daniel et al., 1990 a,b; Lynch et al., 1990; Orland and Carpenter, 1989; Orland, 1990a,b,c,d; Orland et al., 1990), suggest that we are beginning to realize our goal of a reliable and valid simulation tool. A later section of this report reviews progress over the entire project and makes recommendations for future work.

5. EVALUATION OF TOOL FOR OTHER FOREST IMPACTS

Investigate the suitability of computer video-imaging as a means of:

a. simulating various management options.

b. simulating the effects of damage on snow scenes.

Paralleling the development of image processing tools for effecting the insect damage simulations, a feasibility study has been conducted to assess the usefulness of the tool for simulating the impacts named above.

Logging, in one form or another, is the principal means of altering species composition and thus arresting future insect outbreaks. A range of options had been explored in similar studies by the investigator (e.g., Orland, 1989; Orland et al. 1989) and a number of issues raised regarding design of studies using video-imaging technology, and the actual implementation of such studies. In this instance a single option, cable logging, was explored. Images of existing recent cable logging on the Roosevelt National Forest were made available to the project to develop a library of partial images of typical cuts.

In many instances the visual impacts of the logging activity were almost indiscernible. For reasons of demonstrating the usefulness of the computer tools the effects were deliberately exaggerated. A series of images was created illustrating a range of cut widths, distances from the camera, and orientations to the camera line-of-sight. The images accompany this report.

In summer months the visual impact of the insect damage is often reduced by the increased visibility of previously under-storey vegetation, which gives something of an impression of greenness. In winter however, with snow cover, the dead trunks and branches typical of advanced damage stand in stark contrast to the snow. Attempts were made to simulate insect damage on various scenes with damaged areas at different distances from the camera.

Tools used for this portion of the study were standard commercial paint and paste software packages: TIPS (AT&T GSL, 1986); Lumena16 (TimeArts, 1987); IMAGE software (New Image, 1988). However, in order to test the applicability of image processing approaches to these products, the textures in some forest cut patches, and for the impacted areas in the snow scenes were devised to be applied semi-automatically using the pattern function in TIPS. The success of their use suggests the possibility of extending image processing tools to tackle these more difficult problems.

Results and conclusions

Informal reviews indicate that for this narrow range of impacts in Colorado and New Mexico conditions the electronic cut-and-paste technique works well. However, this fails to address the requirement of utility for this development work. In this instance usefulness will be determined by the extent to which individual offices can employ the technology.

6. REVIEW AND IMPLICATIONS

Appraise progress, identify directions for future work. Prepare five-year plan for development and technology transfer.

Improvements in image quality

There have undoubtedly been some advances in quality in the course of the project, some simply a result of better equipment becoming available, others a result of our developing understanding of how to apply the tool to the insect damage simulation problem.

The necessity of standardizing colors across image sets remains. "Toolbox" does not support this function, and its algorithms are rather crude compared with the manipulations necessary.

In addition, while the improvements in color rendering and spatial resolution are tangible, the improvement in quality of simulated insect effects are not easily grasped. To investigate the improvements over time, plots of image mean values were created comparing color changes arising in the pilot study, and phases three and four of the project (Figures 28-39). The most striking feature is the similarity of the results across those three studies. "Good" images were again compared with "bad", and again the within-group differences were greater than between-group. The only promising changes in these patterns are the greater standard deviations associated with "bad" images from the phase 4 (bugs.2) study.

The drawbacks in standardization and image processing functions arise from reliance on a limited function software package.

The present software works only in the RGB color domain -- a bronzing procedure thus involves a number of non-intuitive changes in RGB values to achieve. As indicated in many of the Figures to this paper, between scene variations in both scene color and in change to represent a given damage level are greater than within scene variation between different damage levels, even when the different visual qualities are quite evident. Use of an alternative color space may help to address this problem.

Each of these problems is currently being addressed. Recently, dedicated software and hardware for image processing in an HLS (Hue, Lightness, and Saturation) color space has been introduced at the PC level (Microimages, 1988). HLS offers a more intuitive means of color

manipulation, responding to such directions as "add brown", "darken", and "more color".

Benefits of the image processing approach

The image processing approach developed and described through this project was a unique response to a particular problem. However, having been developed, it offers some opportunities for enhanced modeling and communication. Computer processes such as digital image processing lend themselves to integration with other parts of the resource modeling arena. For instance, integration of this tool with GIS could yield immediate simulations of the visual effects of proposed forest treatments -- a great advantage to forest planners. Elements of this integration have been described elsewhere (e.g., Daniel et al, 1988, 1989, 1990; Itami and Gimblett, 1989; Orland, 1989a,b; Orland et al., 1990).

IDENTIFYING FUTURE DIRECTIONS

For forest managers to plan for a more healthy forest, and to elicit public and political support for such plans, two needs have been identified. First, there is a need for forest managers and planners to predict the responses of public groups to changes in scenic resources, and to plan to minimize any negative impacts. Second, once a proposal is developed, there is a need to communicate the effects of that proposed change to other agencies and public review groups to facilitate decision-making.

Computer-based video simulation has emerged as a tool capable of addressing these needs (Orland, 1986, 1987, 1988, 1989a/b, in press; Daniel and Orland, 1988). Simulated forest images are being used as stimuli in perception modeling studies directed at the first need (Daniel and Orland, 1988; Orland and Daniel, 1988; Orland, 1989c), as well as other studies with a more direct communication goal (Orland and Daniel, 1989; Daniel et al., 1990)

Early studies (Carpenter and Orland, 1989; Larson and Orland, 1987; Orland, 1988; Vining and Orland, 1989; Vining, Ebreo and Orland, 1990)

used computer image editing approaches based on traditional artistic techniques to "paint" or "cut and paste" proposed changes into existing scenes. However, a considerable drawback of this approach was the continuing reliance on expert operators with strong graphic arts training (Orland, 1989b; Orland and Carpenter 1989). In addition, any artistic interpretation was open to criticisms of its validity or bias.

Ideally, a visualization tool should be made available to those involved in day-to-day forest management, without the need to call on special assistance from graphic artists. Visual models should also demonstrate accuracy and validity in representing predicted impacts, and should be capable of creating visual simulations directly from data about the impact, without the intervention of an expert operator.

In response to that need the Imaging Systems Laboratory at the University of Illinois has investigated the potential of tools based on alternative computer modeling approaches.

Surface and solid modeling tools derived from 2- and 3-D Computer-Aided-Drafting, and Geographic Information Systems, offer considerable potential. The dimensional accuracy of such models can be established, and they are easy to manipulate to explore new conditions. However, at this time these tools are highly complex, yet low in their ability to simulate natural colors and textures. The images produced, while visually appealing, lack the realism deemed necessary for public review of forest impact decisions.

The alternative approach described in this report has employed techniques from aerial photo analysis to simulate changes to ground level photography of study sites. Digital image processing has been used to simulate the color and texture changes characteristic of vegetation subjected to insect damage. Scenes of existing impacts have been digitized and then analyzed to assess changes in vegetation color values. Using masks to isolate areas of anticipated impact in presently healthy scenes, digital filters corresponding to the impact severity have been applied to create simulations of future conditions (Daniel and Orland, 1988; Daniel et al.

1990; Orland, 1988a, 1989a/b/c, 1990a, 1990b, in press; Orland and Daniel, 1988,1989).

Review of the resulting images by Forest Service entomologists has supported their validity. However, this work has stretched the capabilities of the equipment currently available and through the course of work, considerable opportunities for improvement in both product and process have been recognized. Future work should pursue some of these anticipated improvements.

Limitations of equipment

At the outset of this project work "state-of-the-art" image digitizing and display tools used a 32,768-color, 16-bit per pixel resolution. In the absence of any commercial equivalents, an image-processing software package was developed in-house (Toolbox, Gupta and Orland, 1988). Two main limitations have been found in using this combination of tools.

1. *The computer hardware and software in use can only address 32 levels of intensity on each of the three video color channels, Red, Green, and Blue. Evaluation studies conducted with forest entomologists (Orland, 1987, 1989a/b/c, 1990a/b; Orland and Daniel, 1989) indicate that visual discriminations made in the field between areas of differing pest impact are much finer than this. In many cases entomologists have wanted to see intermediate values that the computer is unable to show.*

2. *While adequate for our early needs, Toolbox works in a non-intuitive (but easy to program!) RGB (Red, Green, Blue) color space. Users must translate needs such as "darken" into subtractions of Red, Green, and Blue values, "reduce the yellowness" into remove Red and Green -- or add Blue. The spatial filtering techniques enacted in our own software were, by necessity, simple and inflexible and are not adequate for our needs in simulated textural changes in scenic quality. Image processes such as convolutions and contrast stretching have been unavailable without unreasonable amounts of programming.*

Commercial software and hardware products can now address these issues. To address color quality, 24-bits per pixel is an emerging color

standard offering 256 levels on each color channel compared to the previous 32 -- this allows more subtle color changes to be simulated. For example, the Truevision VISTA4M digitizer and color controller specified below can support up to 32-bits per pixel at various screen resolutions. It is now possible to convert to, and edit in, HSI (Hue, Saturation, Intensity) color space which allows operators to respond directly to colors as they perceive them, not as mathematical combinations of Red, Green, and Blue. For the sophisticated image processing needed, good software packages offer a range of functions such as edge detection, convolution filters, and dithering to enhance the user's ability to achieve realistic color and textural effects.

A proposed work plan

Project work is proposed to develop and evaluate improved techniques for simulating the visual impacts of large-scale environmental forest impacts. The vehicle for this development work will continue to be the simulation of the visual effects of forest pests and their control, because of the familiarity of the investigator with these situations. However, it should be noted that the tools in development have applications in other important areas such as harvest modeling, pollution modeling and the effects of climate-change.

1. Upgrade existing technical abilities

Establish 24-bit color processing capability to support simulation of the subtle color and texture changes in forest scenery arising from insect pests. Implement existing simulation procedures using the new tools. Products of this aspect of the study will comprise demonstrations of the visual effects of different forest pest scenarios.

2. Develop and evaluate simulation tools using the wider range of image processing techniques now available

Products will include the identification of procedures to create valid and reliable simulations, and guidelines to communicate those to other users.

3. <u>Conduct studies of the validity of the resulting images for internal agency review and for public forum decision-making</u>

> *Conduct in-depth interviews with forest scientists to assess the quality of simulated scenes as surrogates for on-site visual experience. Responses to participants in scenic preference studies will be analyzed to assess validity of the simulations. Products will include guidelines for use of the tools, and appraisals of their limitations.*

Initial work would be directed at duplicating the functions of our existing software package, <u>Toolbox</u> (Gupta and Orland, 1988). The new tools will be used to develop simulation processes for representing stages of insect damage. The second phase of development will be to make evaluations of alternative processes working within HSI (Hue, Saturation, Intensity), and YIQ (Luminance, Chrominance) color domains.

Evaluation of the images will be conducted in two formats. First, detailed interviews with forest entomologists will be used to establish the realism and accuracy of the resulting simulation products. Second, public perception studies will be conducted and the resulting judgments compared with previous ones based on imagery derived from the earlier technology.

Findings will be disseminated by publication in journals and professional publications, and through forest resource management workshops.

ACKNOWLEDGEMENTS

Research Assistants, Christine Poulsen, and Robert Sullivan; Research programmers, Aloke Gupta, Betty Evans, and Keith Goldberg.

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Figures 1-10. Pilot Study -- Study phase I

Comparisons of pixel values, original and manipulated images

"Good" signifies the three best images from the study set, based on a subjective judgement
"Bad" signifies the three worst images, again based on a subjective judgement
Open symbols represent the values found in "Good" images, Closed symbols represent those in "Bad" images.
Pixel values are mean color values computed for a target area of the subject image using "Toolbox" software.

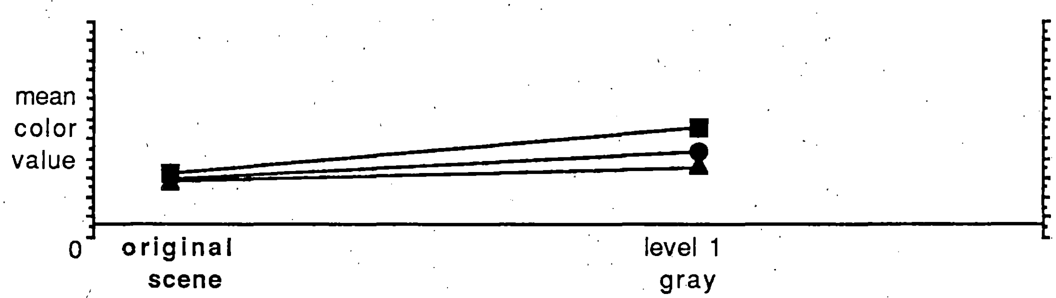
Image file names:

All original photography was taken in New Mexico, in the Red River area of the Carson National Forest.

FS**LOW**2 indicates an image with LOW evidence of insect damage, FS**MLOW** indicates Medium LOW, FS**MHIGH** indicates Medium HIGH.

LOW2, MLOW2 & MHIGH1 were judged "Good" in rendition of increased insect damage, compared with the complete set of images, LOW3, MLOW1 & MHIGH2 were judged "Bad"

Format of figures:



Observations:

For all images the simulated "Graying" of fir species mortality is associated with a drop in Green pixel values and a rise in Red and Blue values -- this corresponding to the expected changes from predominantly green vegetation to gray.

Comparisons between values recorded for Good and Bad images reveal no obvious differences in the color manipulations used.

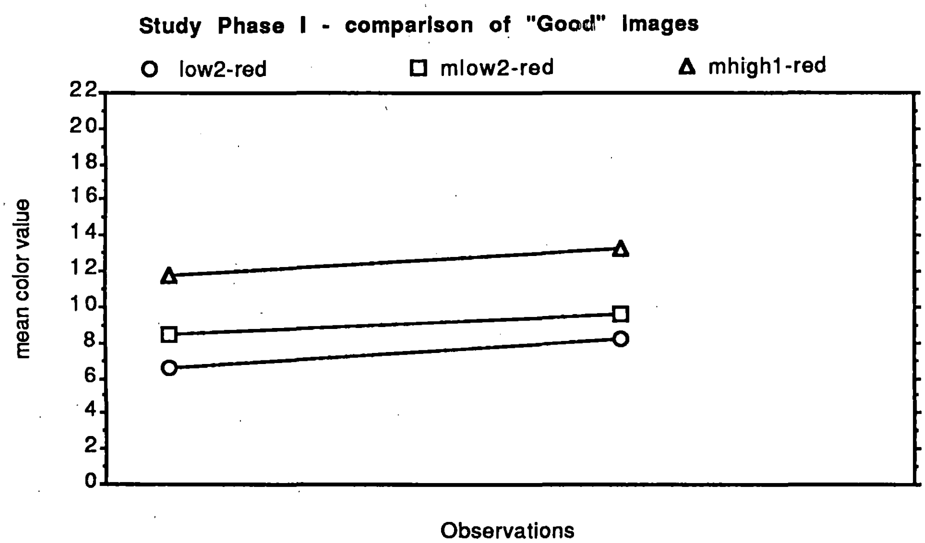


Figure 1. Comparison of pixel values, original and manipulated images "Good" images, Red channel

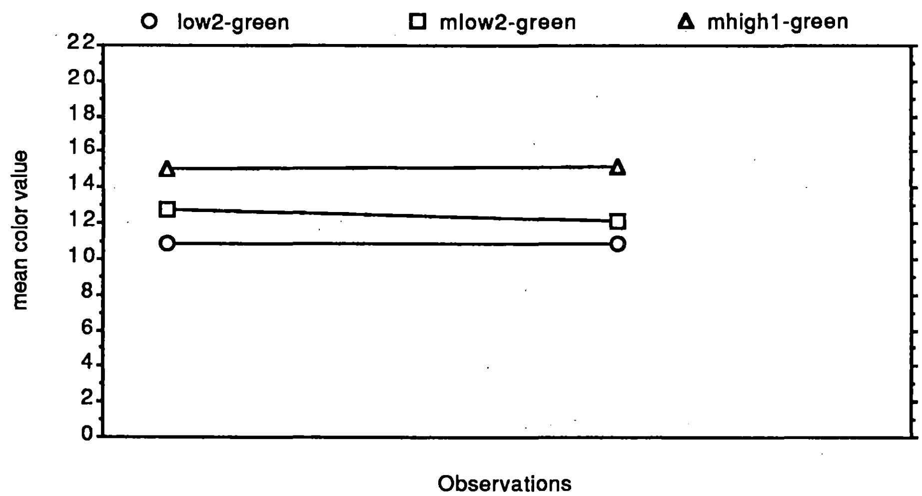


Figure 2. Comparison of pixel values, original and manipulated images "Good" images, Green channel

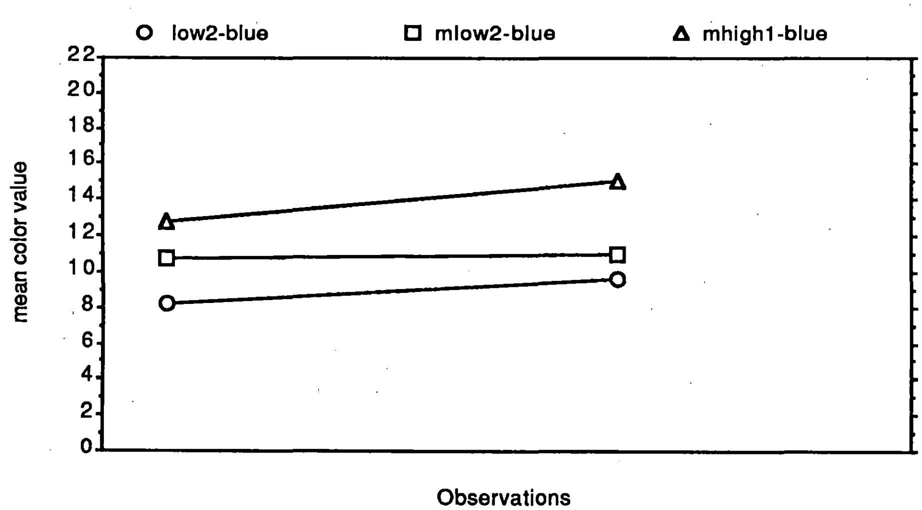


Figure 3. Comparison of pixel values, original and manipulated images "Good" images, Blue channel

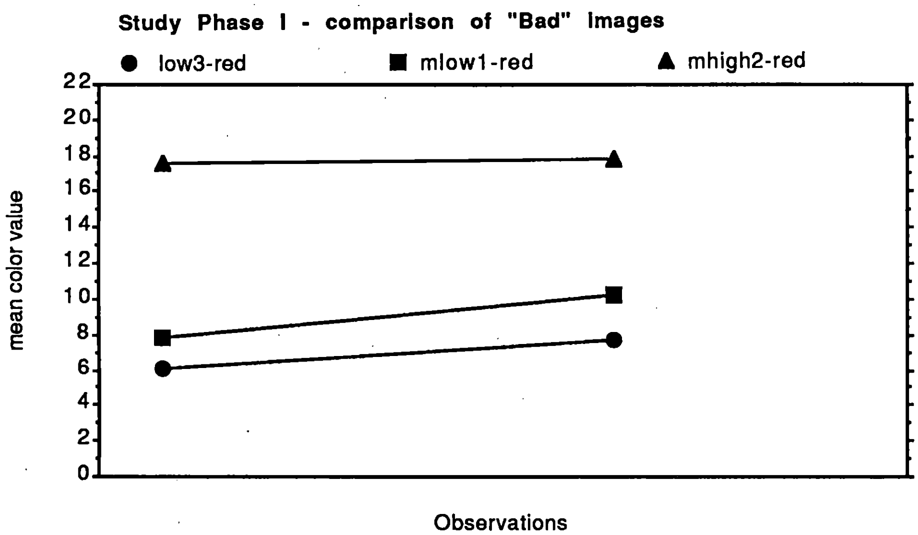


Figure 4. Comparison of pixel values, original and manipulated images "Bad" images, Red channel

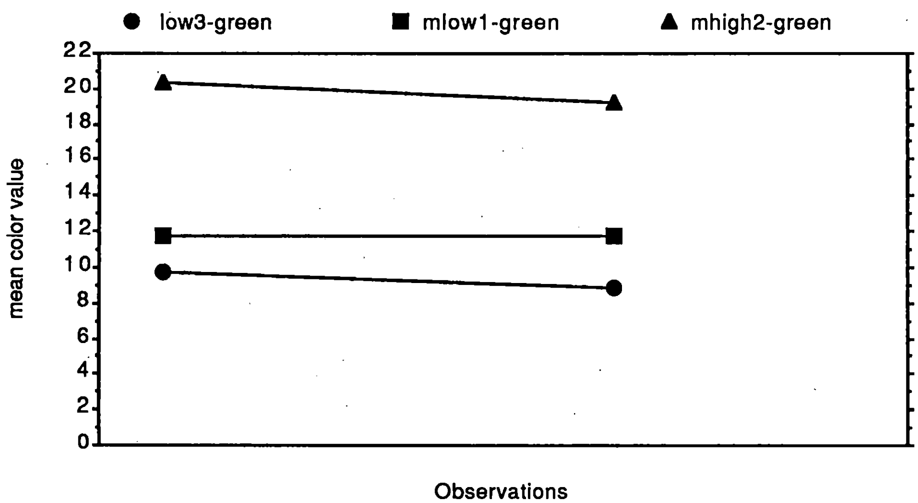


Figure 5. Comparison of pixel values, original and manipulated images "Bad" images, Green channel

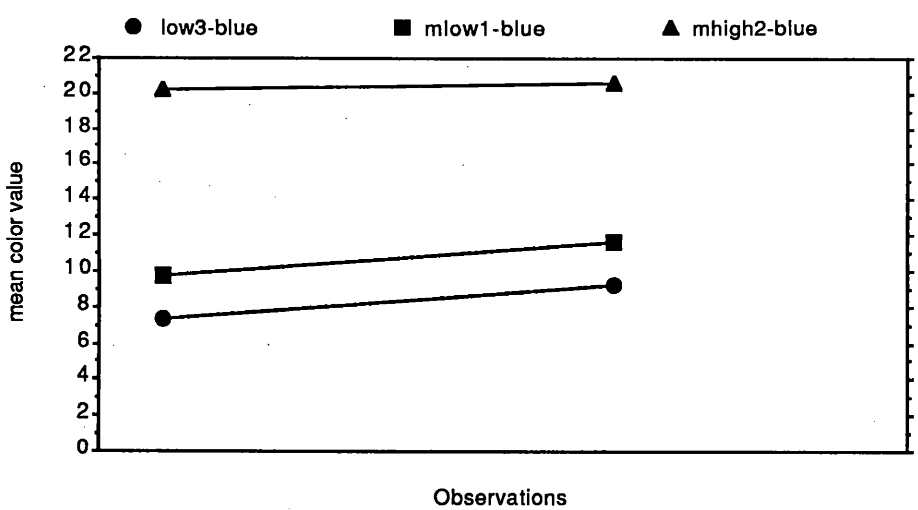


Figure 6. Comparison of pixel values, original and manipulated images "Bad" images, Blue channel

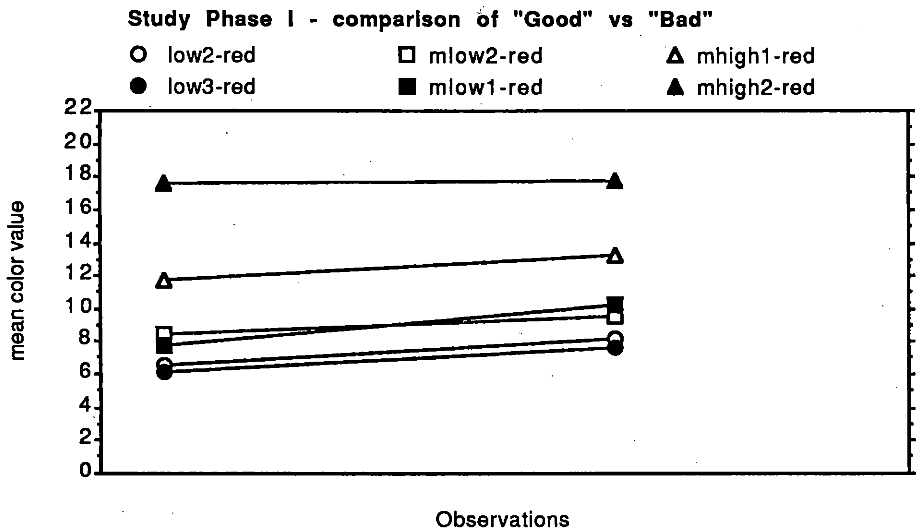


Figure 7. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Red channel

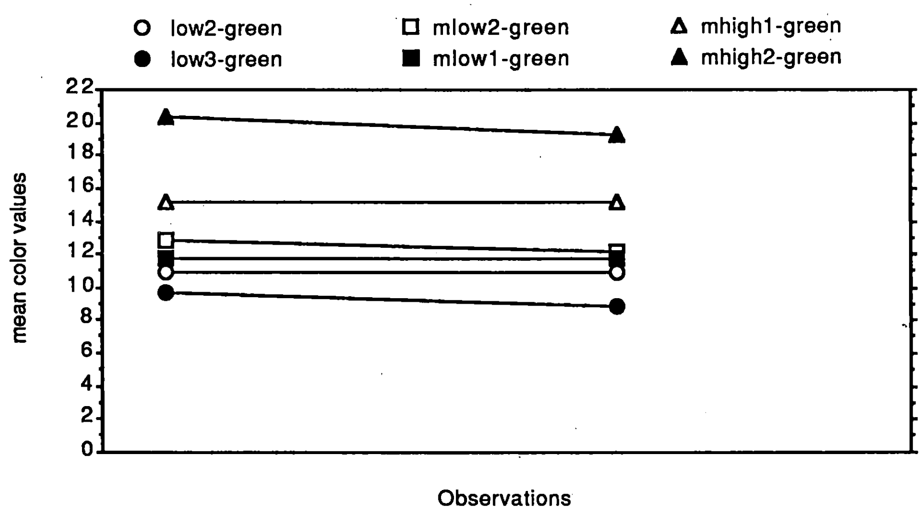


Figure 8. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Green channel

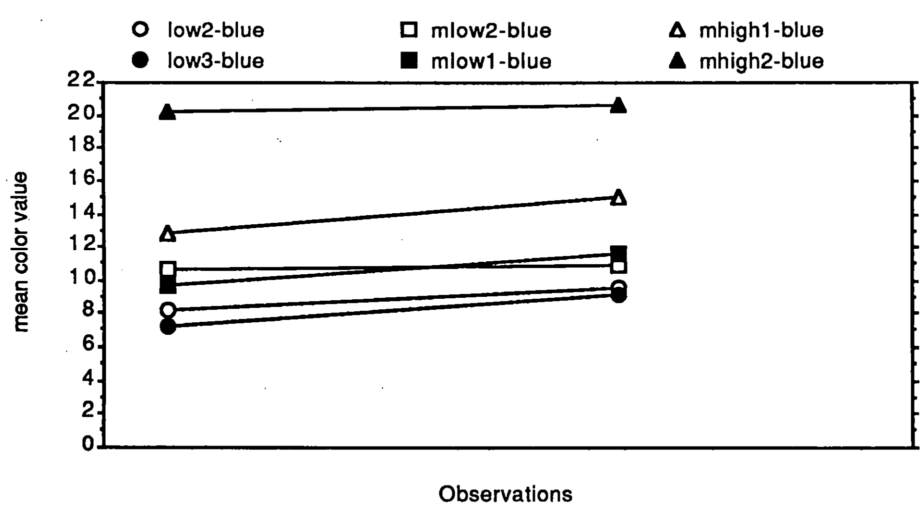


Figure 9. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Blue channel

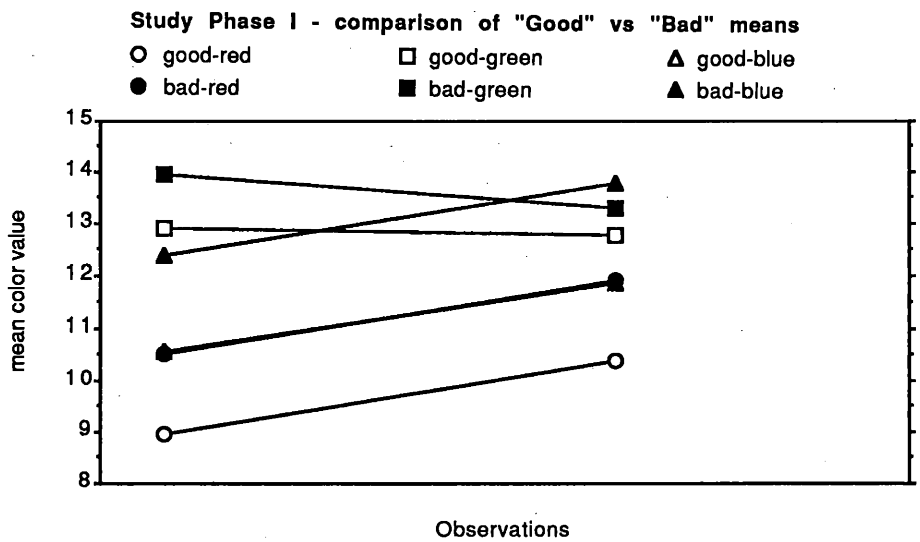


Figure 10. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, All color channels

Figures 11-20. Study phase II

Comparisons of pixel values, original and manipulated images

"Good" signifies the three best images from the study set, based on a subjective judgement
"Bad" signifies the three worst images, again based on a subjective judgement
Open symbols represent the values found in "Good" images, Closed symbols represent those in "Bad" images.
Pixel values are mean color values computed for a target area of the subject image using "Toolbox" software.

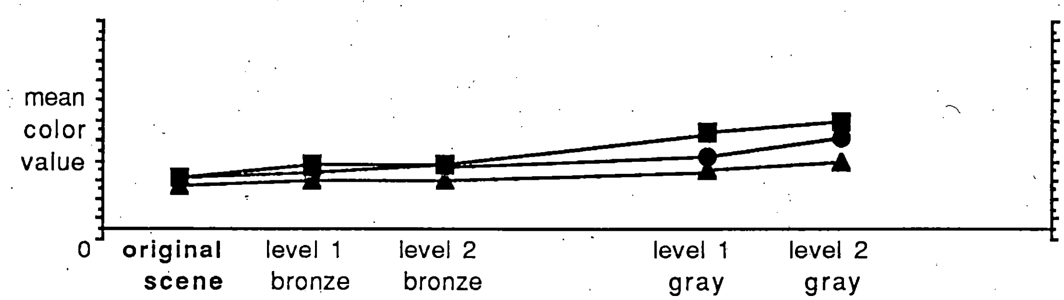
Image file names:

All original photography was taken in New Mexico, in the Red River area of the Carson National Forest.

BU**AP**03 - Agua Piedra, Campground
BU**RP**15 - Rio Pueblo, Mile marker 52
BU**RP**19 - Rio Pueblo, Mile marker 48, Mill
BU**RP**23 - Rio Pueblo, Campground
BU**RP**25 - Rio Pueblo, Elks Lodge, high point
BU**VP**02 - Las Conchas, Trailhead, IFP demo

BUAP03, BURP15, BURP19 were judged "Good" in rendition of increased insect damage, compared with the complete set of images, BURP23, BURP25, BUVP02 were judged "Bad"

Format of figures:



For all images two levels of "Bronzing", indicating insect defoliation, were simulated, and two levels of "Graying" indicating fir species mortality.

Observations:

The bronze coloration caused by early stages of defoliation is associated with a drop in Blue pixel values and a rise in Red values -- this corresponding to the expected changes from predominantly blue-green vegetation to reddish bronze. The

graying associated with tree mortality is seen in a rise in Blue from original values and a parallel small increase in Red -- increase in these two colors will lighten the predominant Green values, thus achieving the desired silvery gray.

Comparisons between values recorded for Good and Bad images reveal no obvious differences in the color manipulations used.

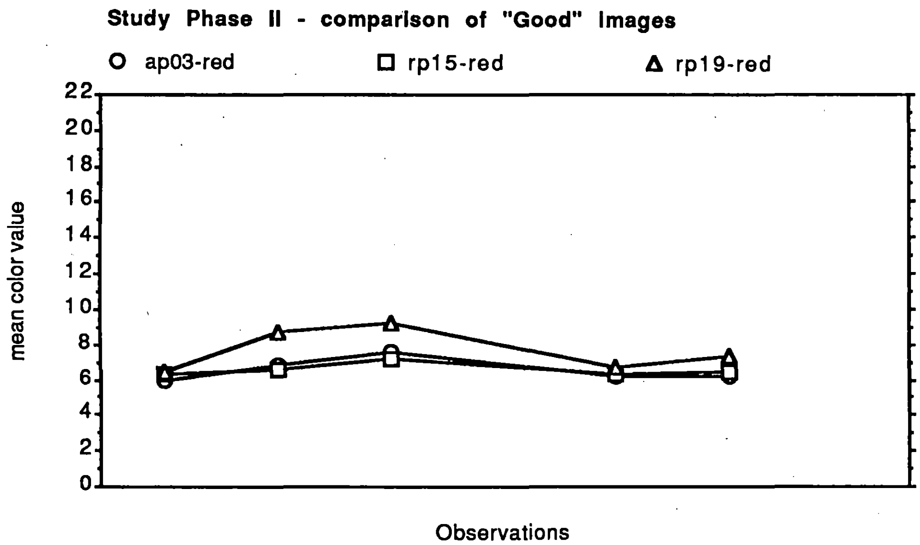


Figure 11. Comparison of pixel values, original and manipulated images "Good images; Red channel

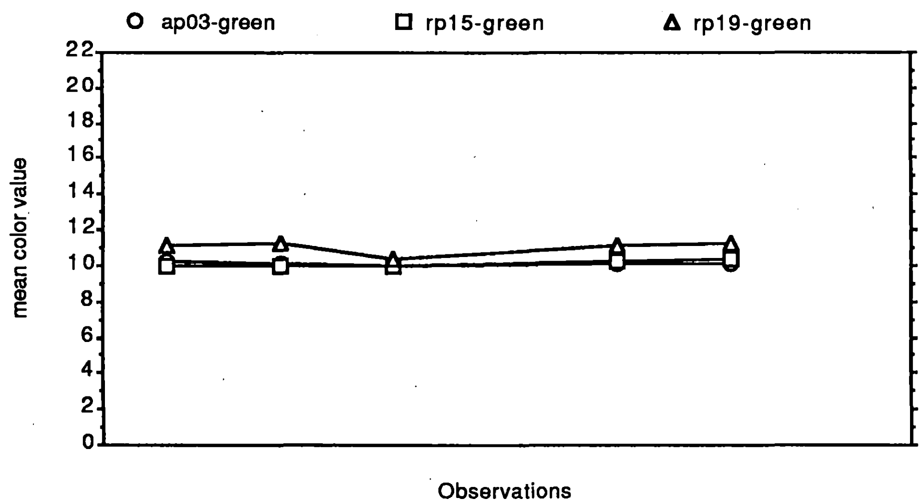


Figure 12. Comparison of pixel values, original and manipulated images "Good" images, Green channel

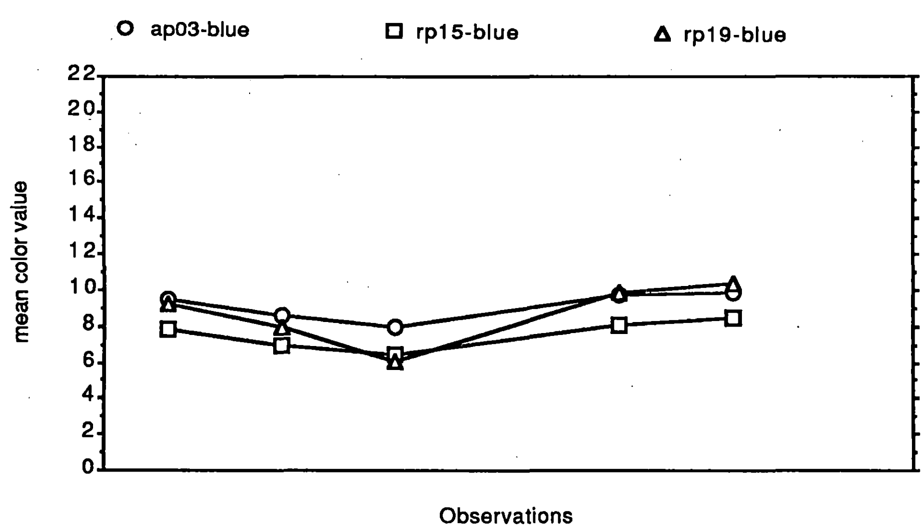


Figure 13. Comparison of pixel values, original and manipulated images "Good" images, Blue channel

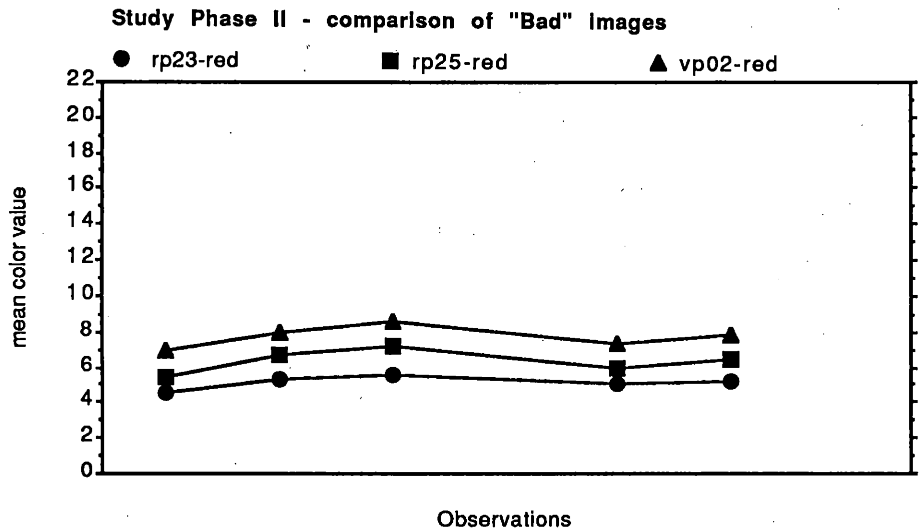


Figure 14. Comparison of pixel values, original and manipulated images "Bad" images, Red channel

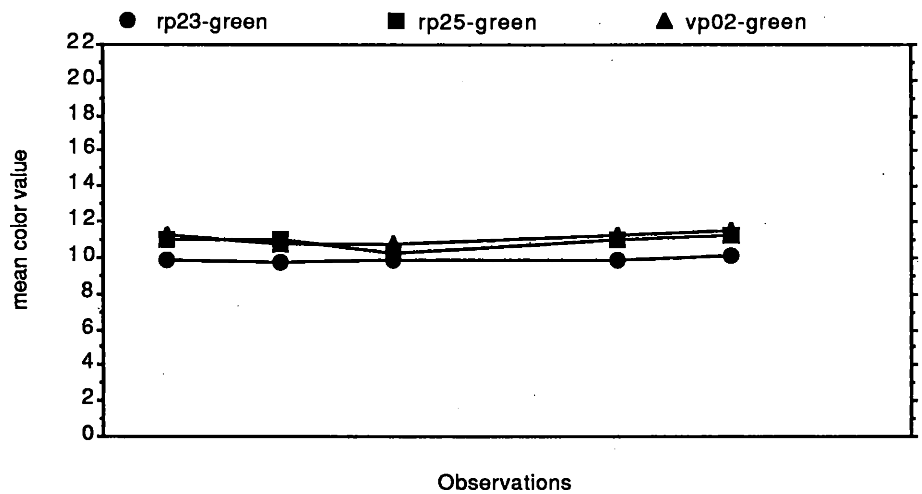


Figure 15. Comparison of pixel values, original and manipulated images "Bad" images, Green channel

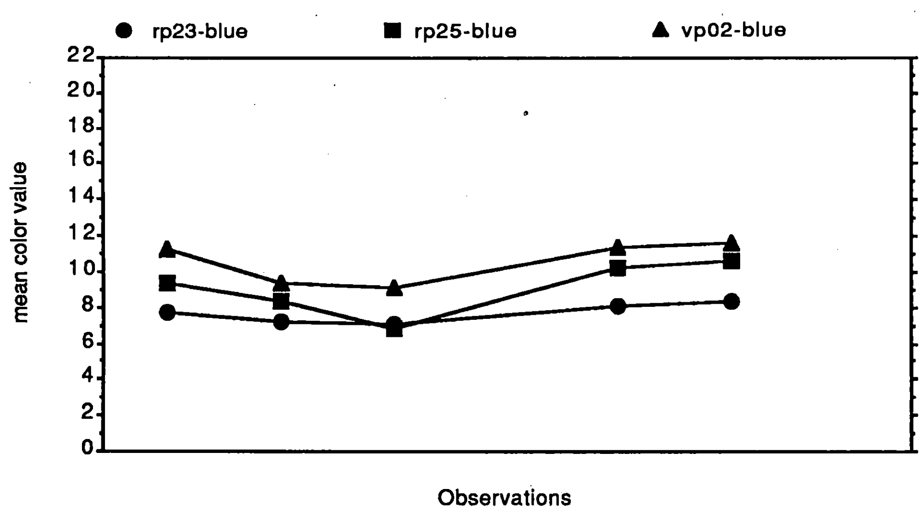


Figure 16. Comparison of pixel values, original and manipulated images "Bad" images, Blue channel

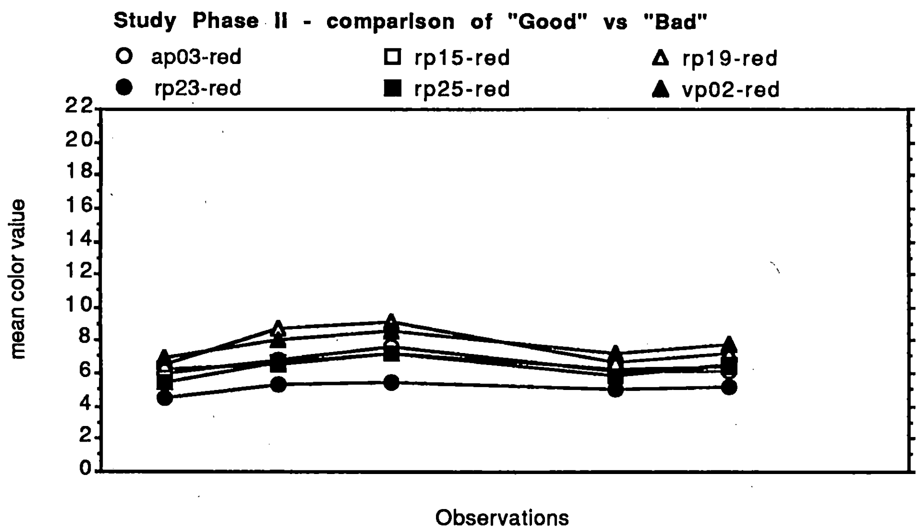


Figure 17. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Red channel

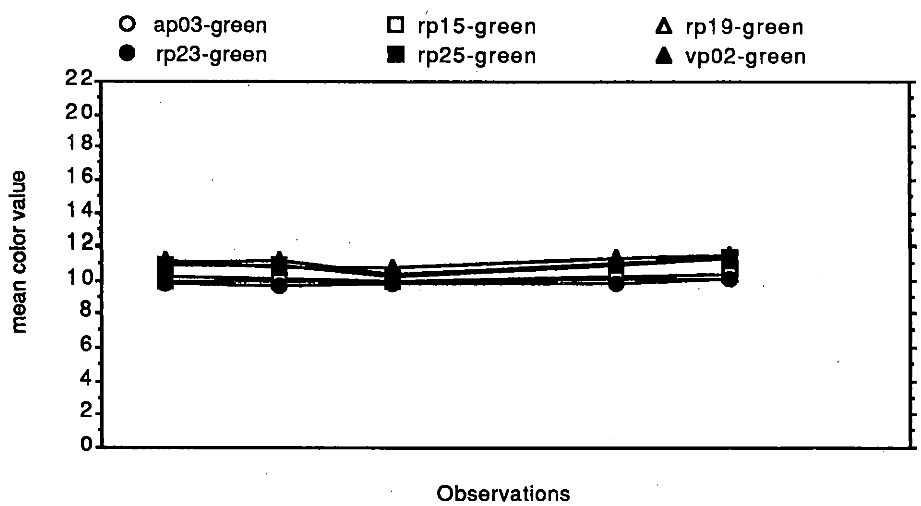


Figure 18. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Green channel

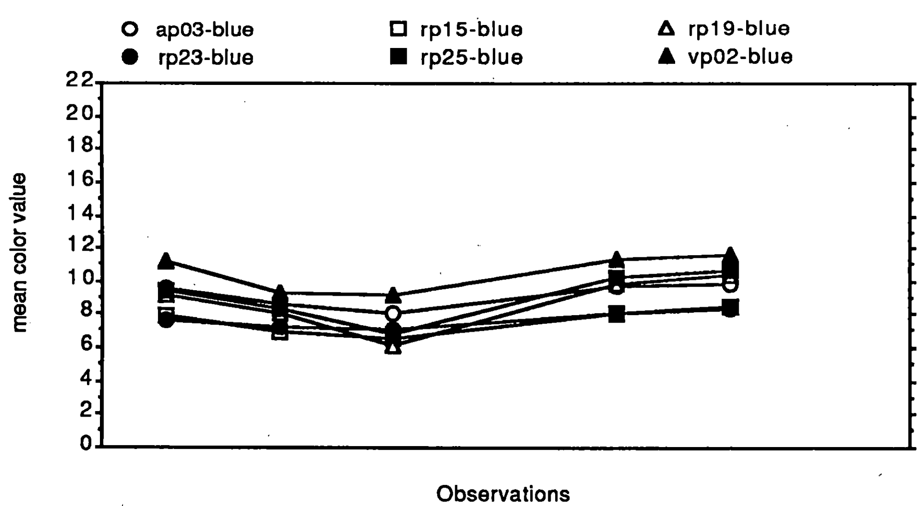


Figure 19. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, Blue channel

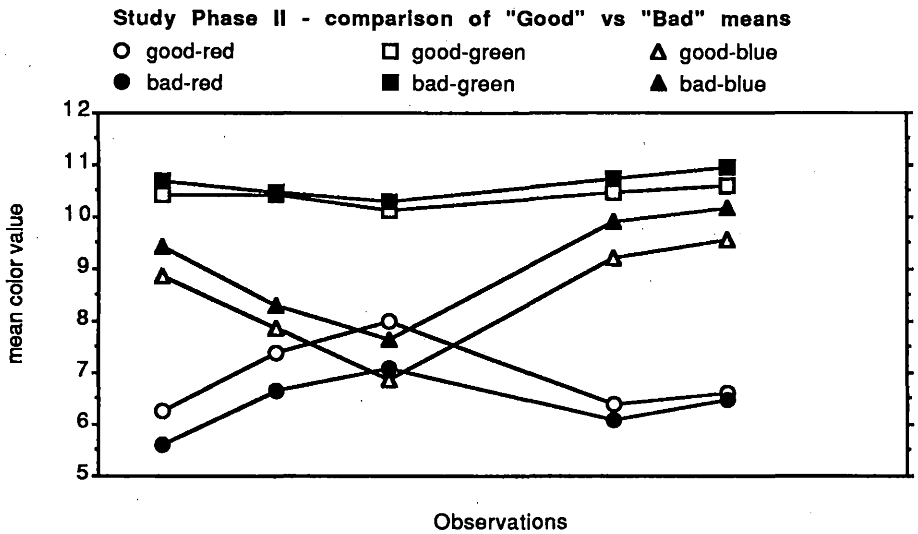


Figure 20. Comparison of pixel values, original and manipulated images "Good" vs. "Bad" images, all color channels

Figures 21-35. Study phase III

Comparisons of pixel values, original and manipulated images

"Good" signifies the three best images from the study set, based on a subjective judgement
"Bad" signifies the three worst images, again based on a subjective judgement
Open symbols represent the values found in "Good" images, Closed symbols represent those in "Bad" images.
Pixel values are mean color values computed for a target area of the subject image using "Toolbox" software.

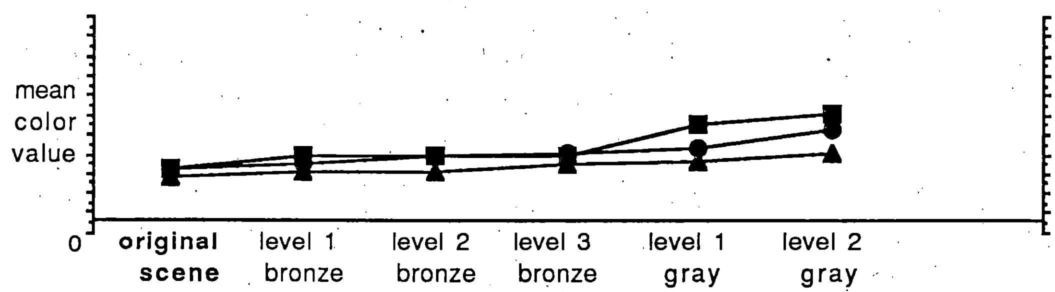
Image file names:

All original photography was taken in New Mexico, in the Red River area of the Carson National Forest.

B2**AP**03 - Agua Piedra, Campground
B2**RP**23 - Rio Pueblo, Campground
B2**RP**30 - Rio Pueblo, Forest Road X, NM3
B2**RP**19 - Rio Pueblo, Mile marker 48, Mill
B2**RP**25 - Rio Pueblo, Elks Lodge, high point
B2**VP**02 - Las Conchas, Trailhead, IFP demo

B2AP03, B2RP23, B2RP30 were judged "Good" in rendition of increased insect damage, compared with the complete set of images, B2RP19, B2RP25, B2VP02 were judged "Bad"

Format of figures:



For all images three levels of "Bronzing", indicating insect defoliation, were simulated, and two levels of "Graying" indicating fir species mortality.

Observations:

For "Good" images, Bronzing is associated with a slight drop in Green pixel values and a rise in Red values -- this corresponding to the expected changes from predominantly green vegetation to reddish bronze. Graying is seen as a small increase in Red from

the values of the original condition and a small increase in Blue -- increase in these two colors will lighten the predominant Green and Red values (of green-yellow vegetation), thus achieving the desired silvery gray.

Comparisons between values recorded for Good and Bad images reveal large differences in the color values of the original images. "Bad" images had Red, Green, and Blue values higher by 50% than those of "Good" images. Subsequent manipulations brought the values closer together. Nevertheless, the pattern of color manipulations associated with "Good" images reflects the intuitive expectation, while the changes to "Bad" images do not.

Note - comparisons with Study phase II (see Figures 31-35)

	II	III
AP03	Good	Good
RP15	Good	
RP19	Good	Bad
RP23	Bad	Good
RP25	Bad	Bad
RP30		Good
VP02	Bad	Bad

In general, Blue and Green values were higher for Study phase II. This was an expected consequence of digitizing via a video camera source -- video images display high levels of Blue and Green light wavelengths. Nevertheless, there is no apparent pattern of pixel values indicating why an image would appear Good or Bad.

Study Phase III - comparison of "Good" images

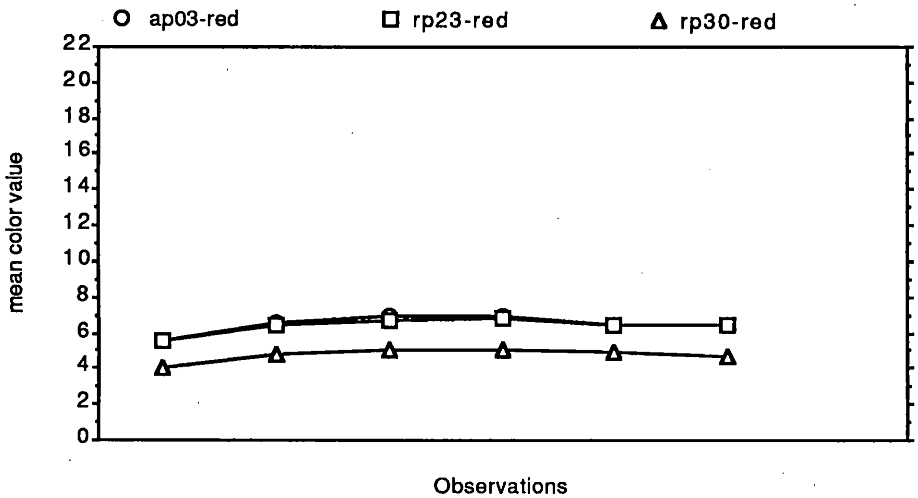


Figure 21. Comparison of pixel values, original and manipulated images "Good" images, Red channel

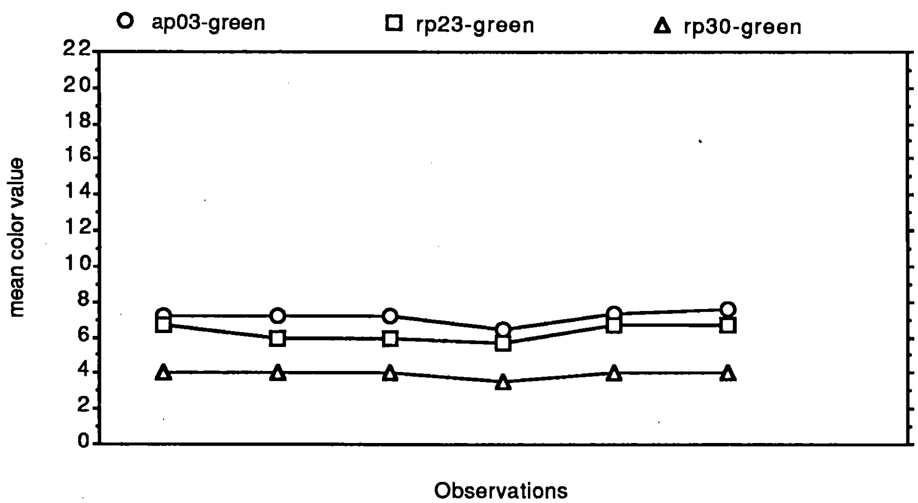


Figure 22. Comparison of pixel values, original and manipulated images "Good" images, Green channel

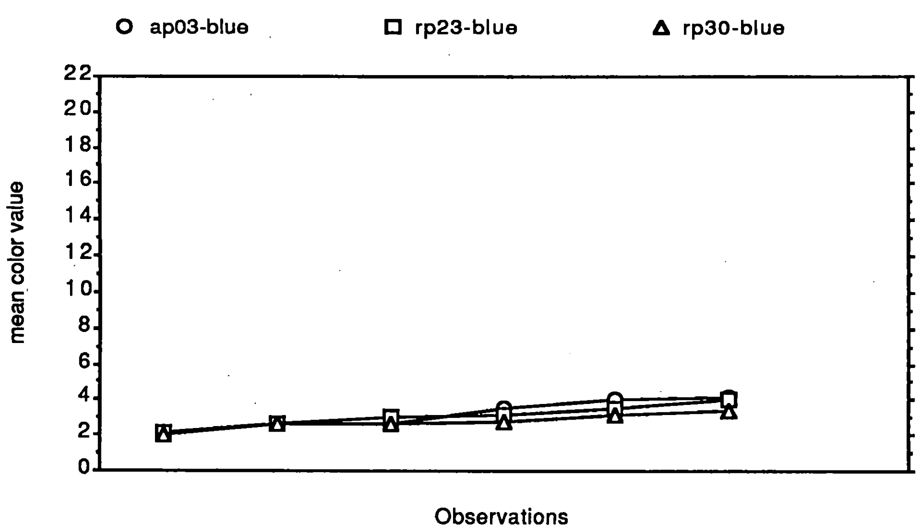


Figure 23. Comparison of pixel values, original and manipulated images "Good" images, Blue channel

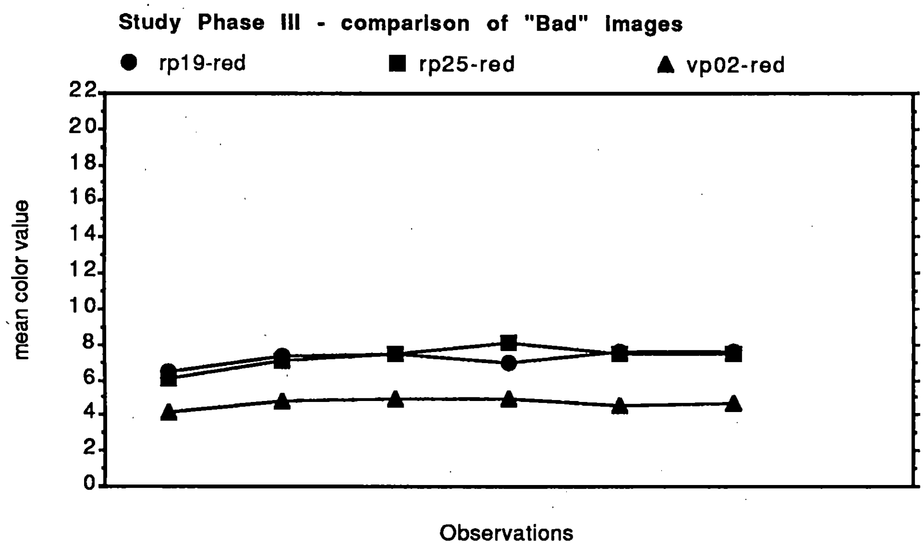


Figure 24. Comparison of pixel values, original and manipulated images "Bad" images, Red channel

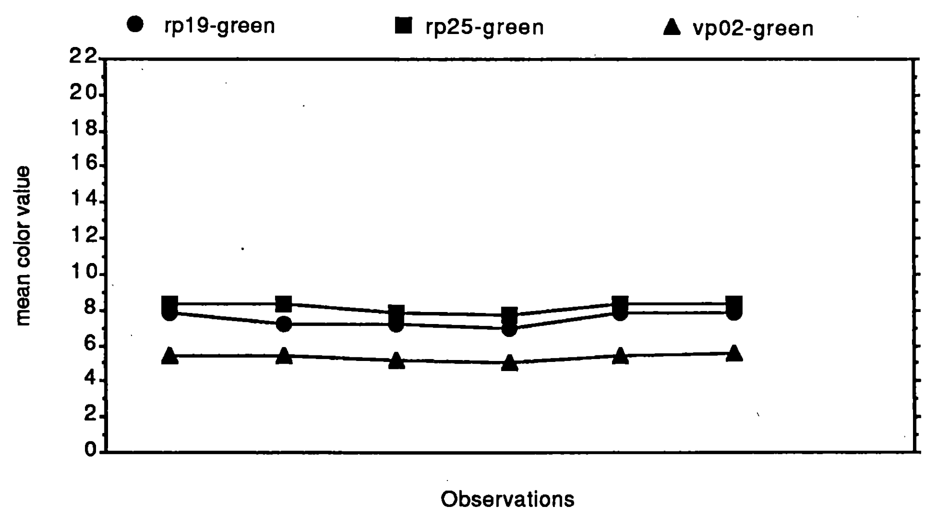


Figure 25. Comparison of pixel values, original and manipulated images "Bad" images, Green channel

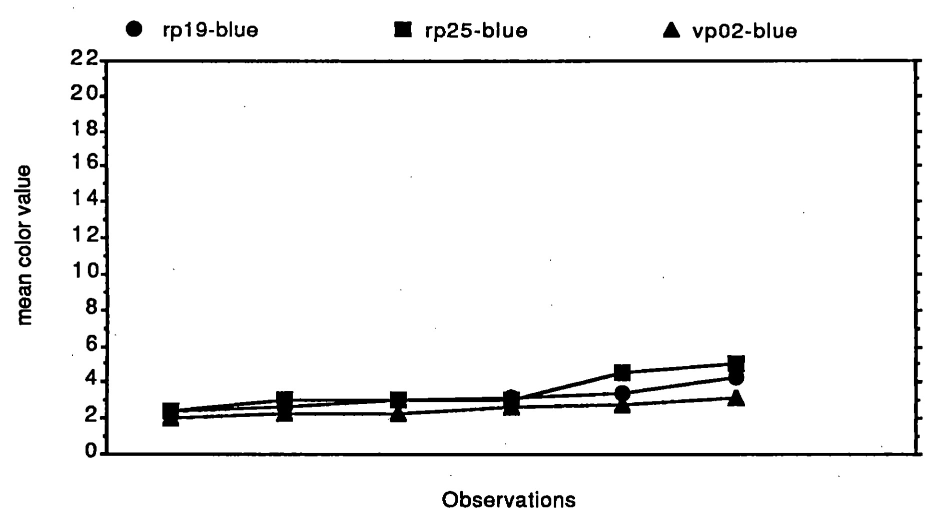


Figure 26. Comparison of pixel values, original and manipulated images "Bad" images, Blue channel

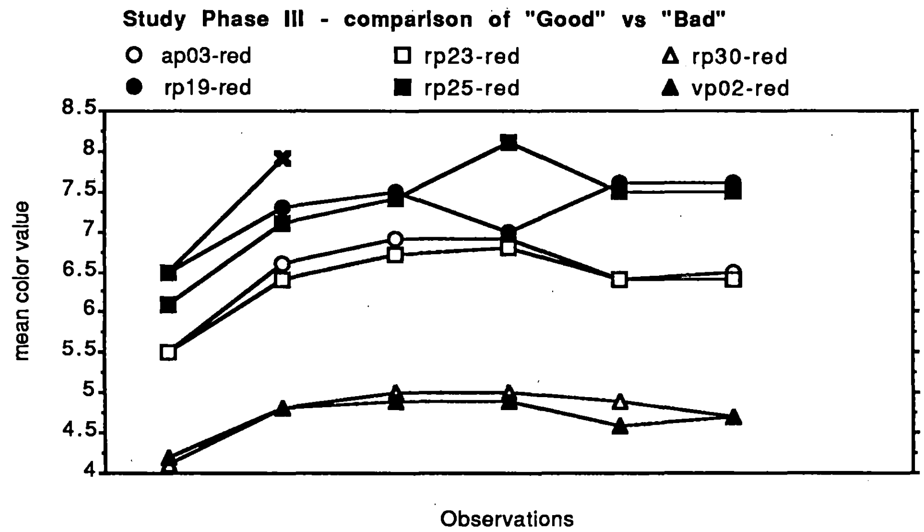


Figure 27. Comparison of pixel values, original and manipulated images "Good" and "Bad" images, Red channel

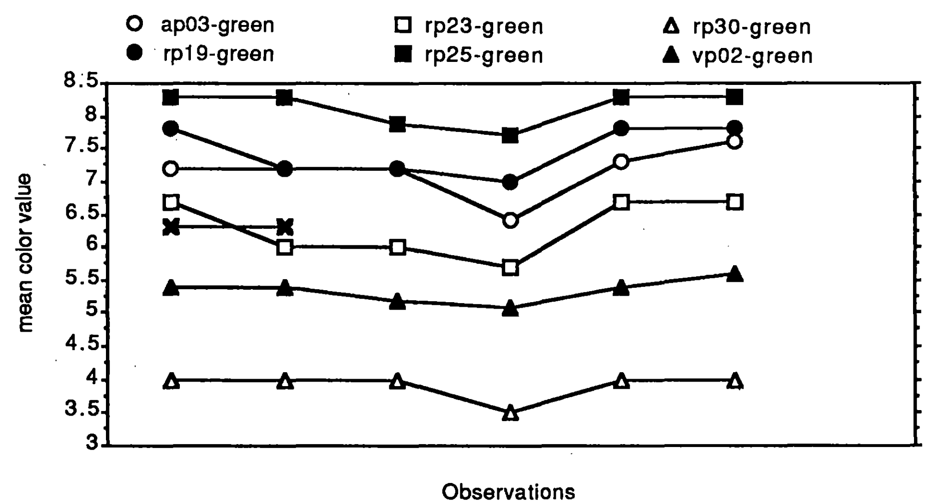


Figure 28. Comparison of pixel values, original and manipulated images "Good" and "Bad" images, Green channel

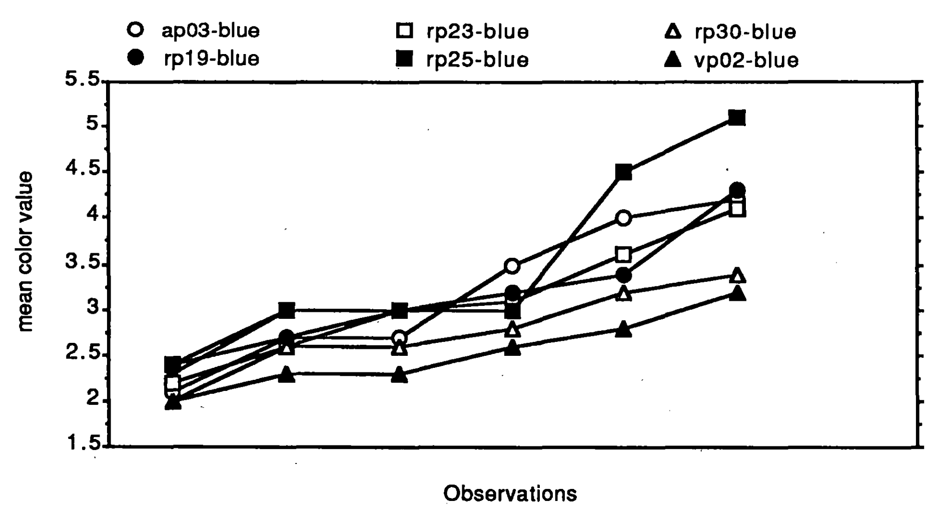


Figure 29. Comparison of pixel values, original and manipulated images "Good" and "Bad" images, Blue channel

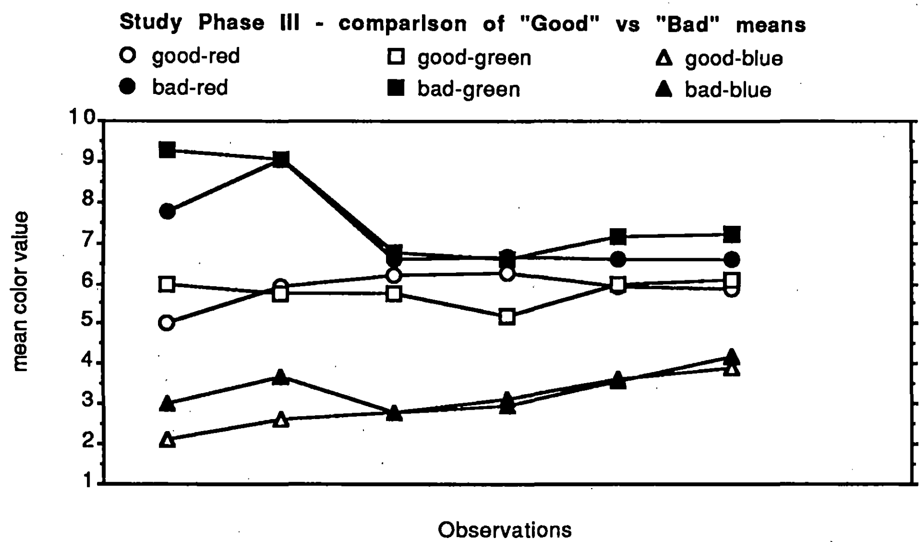


Figure 30. Comparison of pixel values, original and manipulated images "Good" and "Bad" images, all color channels

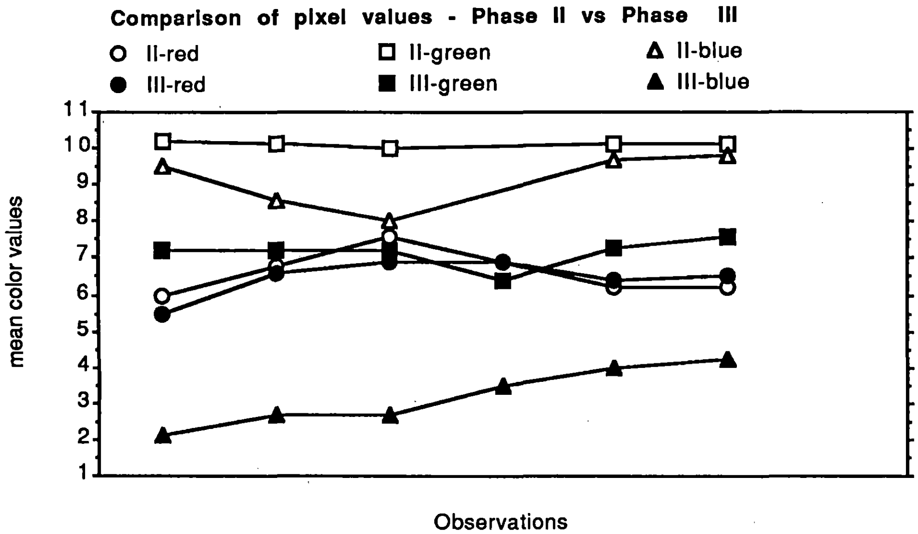


Figure 31. Comparison of pixel values, original and manipulated images
Agua Piedra 03 -- II vs III (Good vs Good)
II - open; III - solid

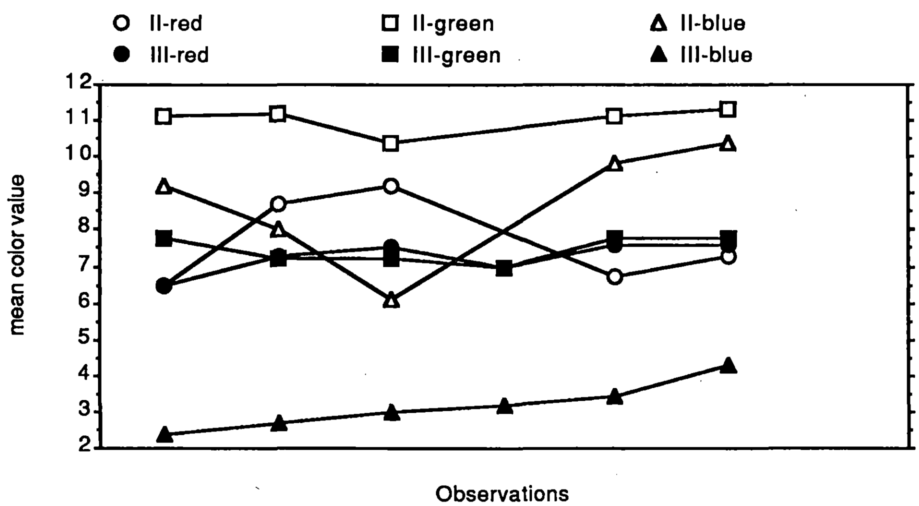


Figure 32. Comparison of pixel values, original and manipulated images
Rio Pueblo 19 -- II vs III (Good vs Bad)
II - open; III - solid

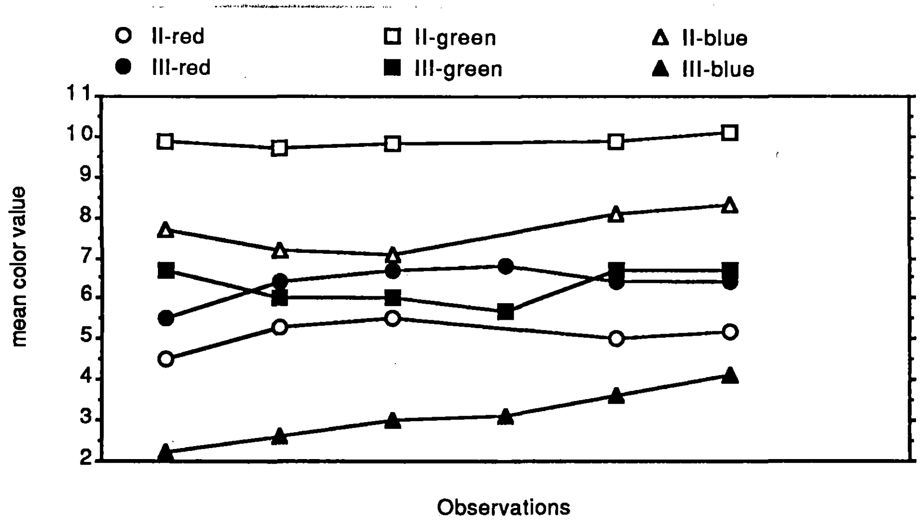


Figure 33. Comparison of pixel values, original and manipulated images
Rio Pueblo 23 -- II vs III (Bad vs Good)
II - open; III - solid

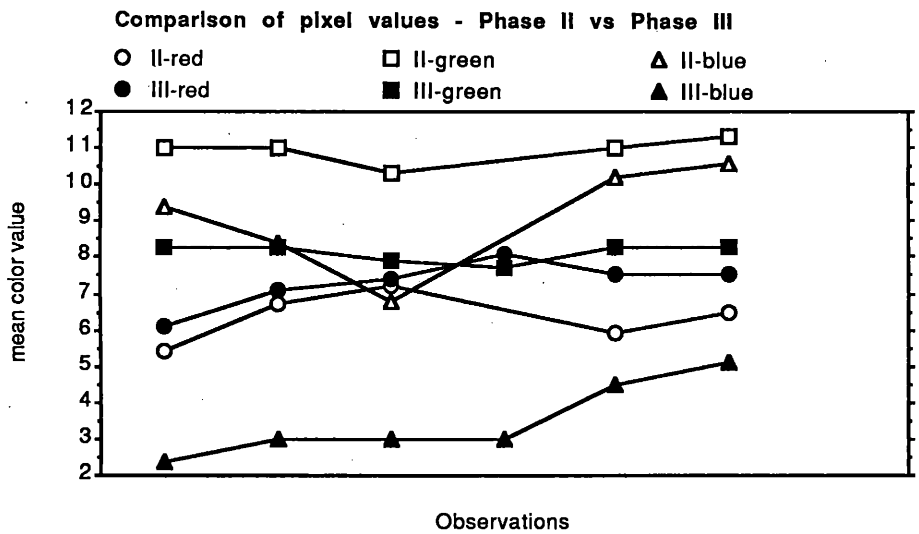


Figure 34. Comparison of pixel values, original and manipulated images
Rio Pueblo 25 -- II vs III (Bad vs Bad)
II - open; III - solid

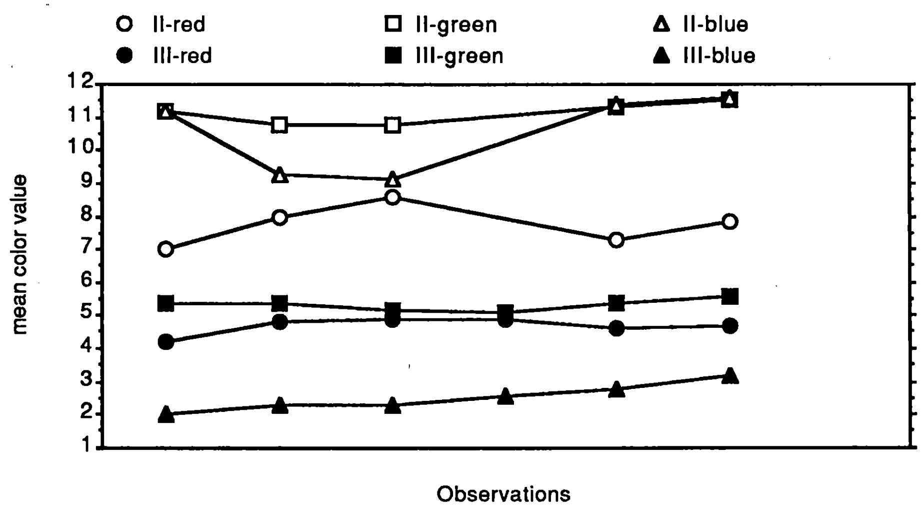
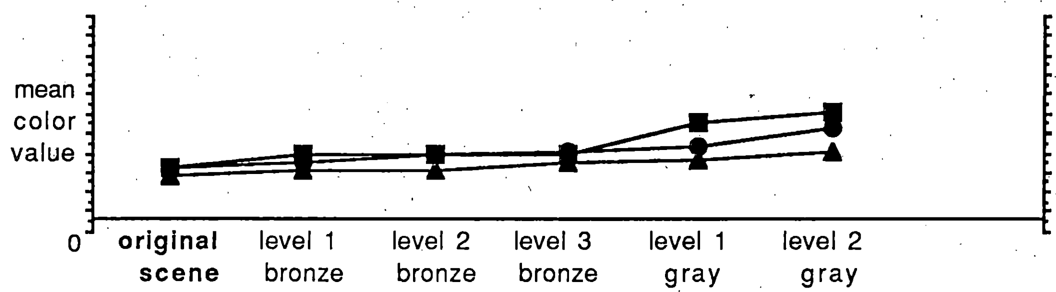


Figure 35. Comparison of pixel values, original and manipulated images
Las Conchas 02-- II vs III (Bad vs Bad)
II - open; III - solid

Figures 36-51. Comparisons of pixel values across Study phases

I through **III** indicate the Study phase. Open symbols represent the values found in "Good" images, Closed symbols represent those in "Bad" images.
Pixel values are mean color values computed for a target area of the subject image using "Toolbox" software.

Format of figures:



Observations:

Comparisons between mean pixel values recorded for Good and Bad images, for the three stages of study, reveal no apparent patterns of differences in color values.

To investigate the values further, Standard Deviations were plotted, to look for possible greater variability in one set of values vs others (Figures 42-47). Images digitized using a scanner exhibit greater apparent clarity and contrast than those created via video camera. Comparisons of histograms for each type reveal, however, a similar range of pixel values for each -- and hence would be measured similar in contrast. The difference lies in the variability, in scanned images, of pixel value in a small area -- video-origin images exhibit more "blending" of values between adjacent pixels. The visual consequence is increased "graininess", and apparent contrast.

"Bad" images from Study phase III exhibit greater standard deviations than "Good" images, suggesting an area needing more investigation.

Figure 51 plots "Good" vs "Bad" values for each Study phase, showing all color channels and all treatments. The absence of discernible differences in pixel values associated with image quality is illustrated by the linear relationships of "Good" and "Bad" values, for Study phases I and II. The plot of values for Study phase III shows a departure from this pattern and indicates the desirability of further research of these issues.

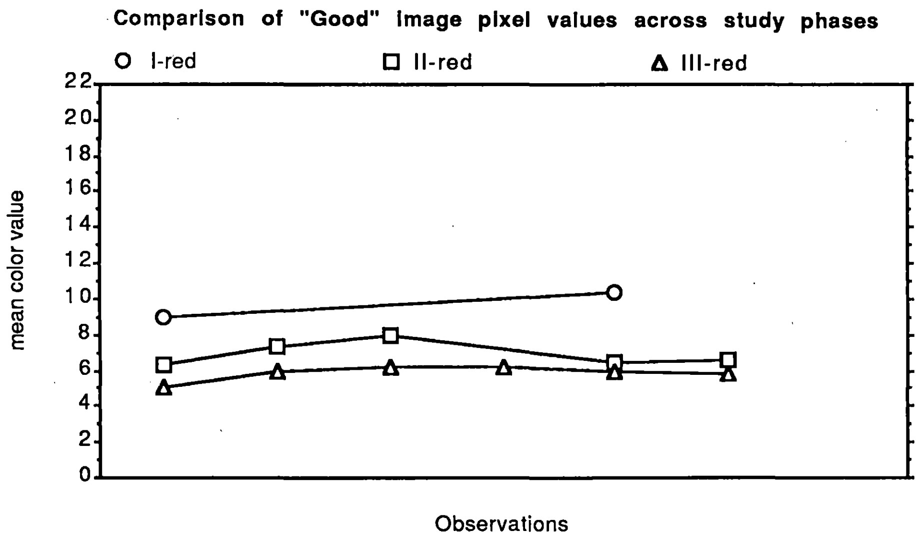


Figure 36. Comparison of pixel values, between study phases "Good" images, Red values

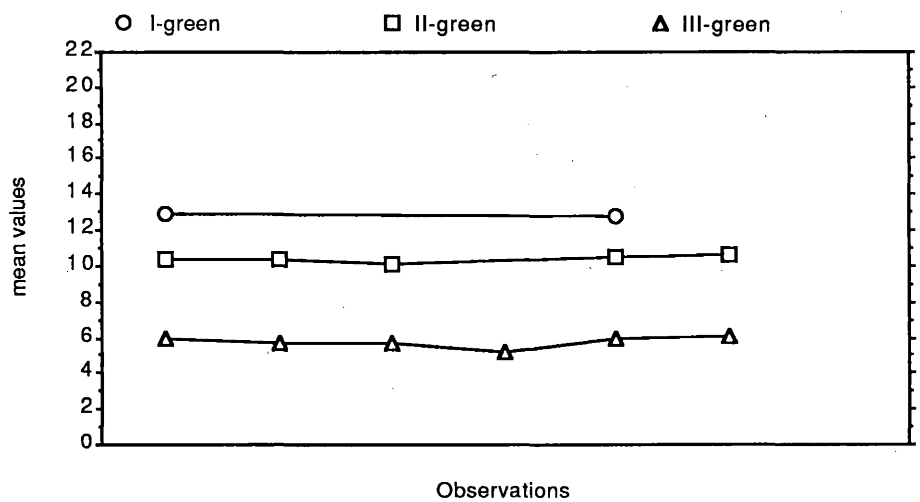


Figure 37. Comparison of pixel values, between study phases "Good" images, Green values

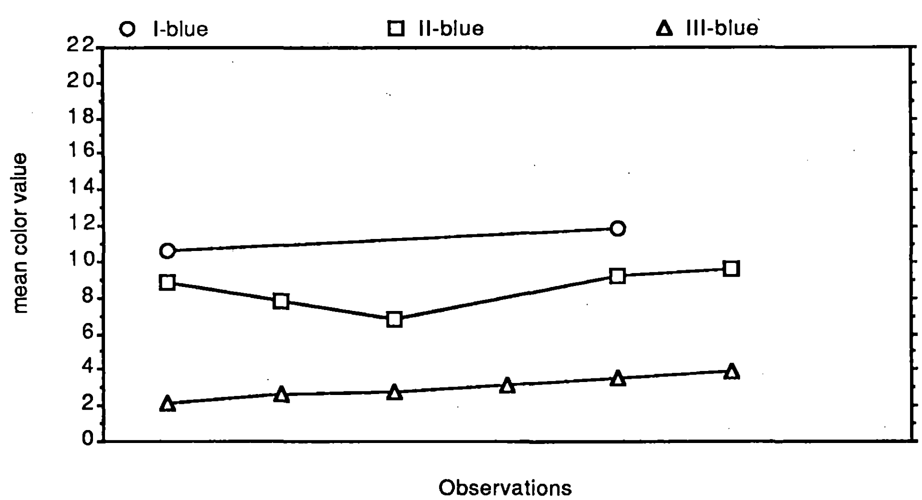


Figure 38. Comparison of pixel values, between study phases "Good" images, Blue values

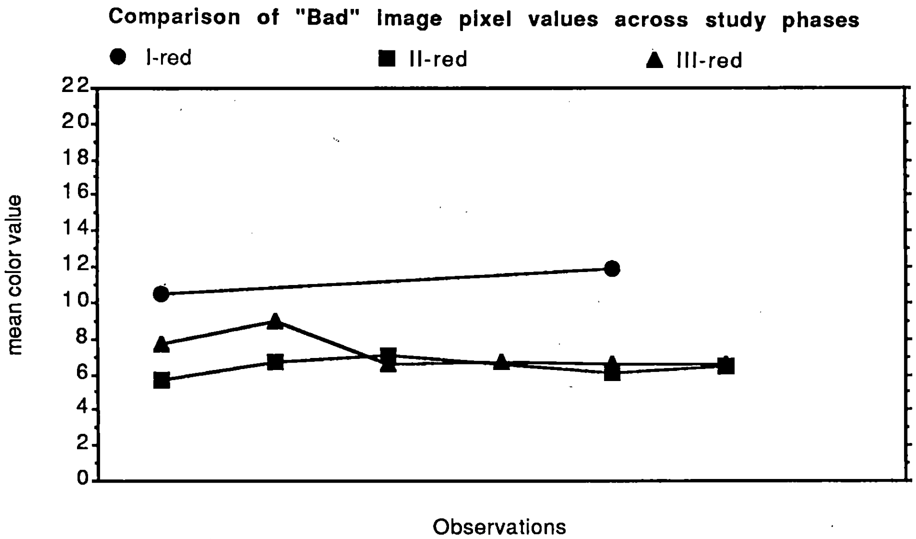


Figure 39. Comparison of pixel values, between study phases "Bad" images, Red values

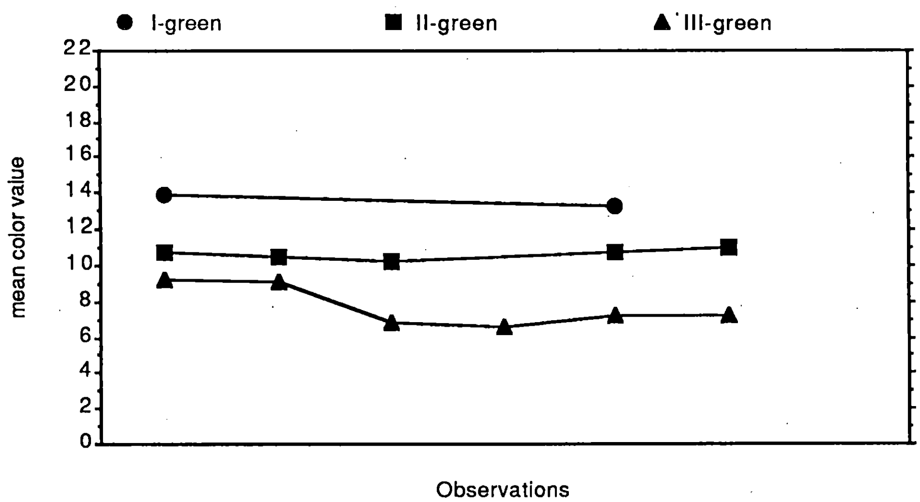


Figure 40. Comparison of pixel values, between study phases "Bad" images, Green values

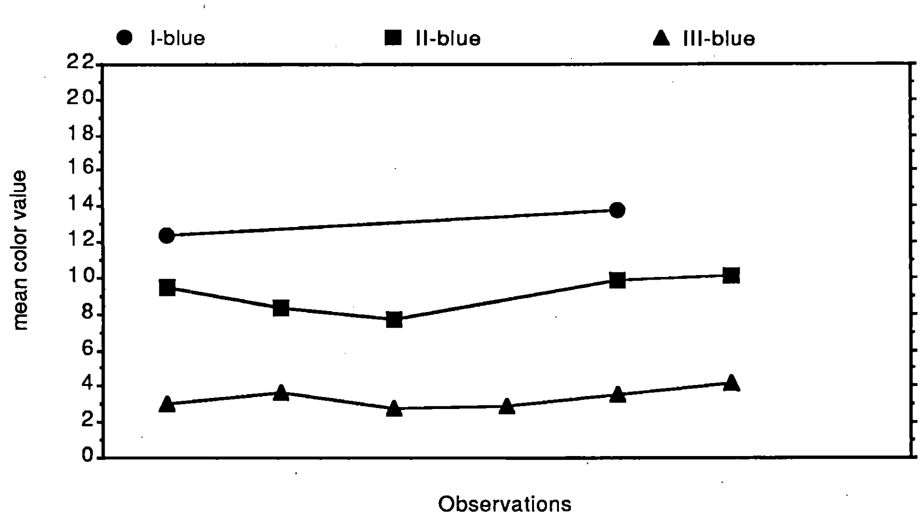


Figure 41. Comparison of pixel values, between study phases "Bad" images, Blue values

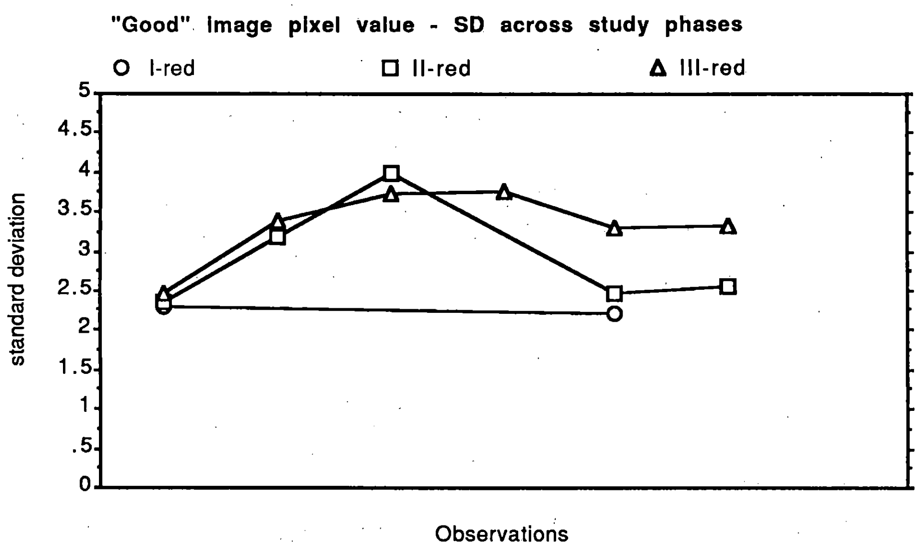


Figure 42. Comparison of pixel value standard deviations, between study phases
"Good" images, Red values

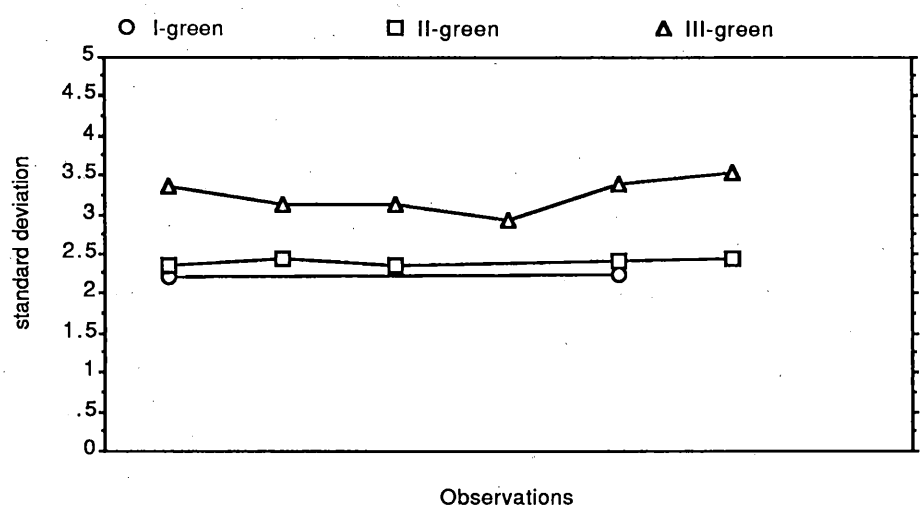


Figure 43. Comparison of pixel value standard deviations, between study phases
"Good" images, Green values

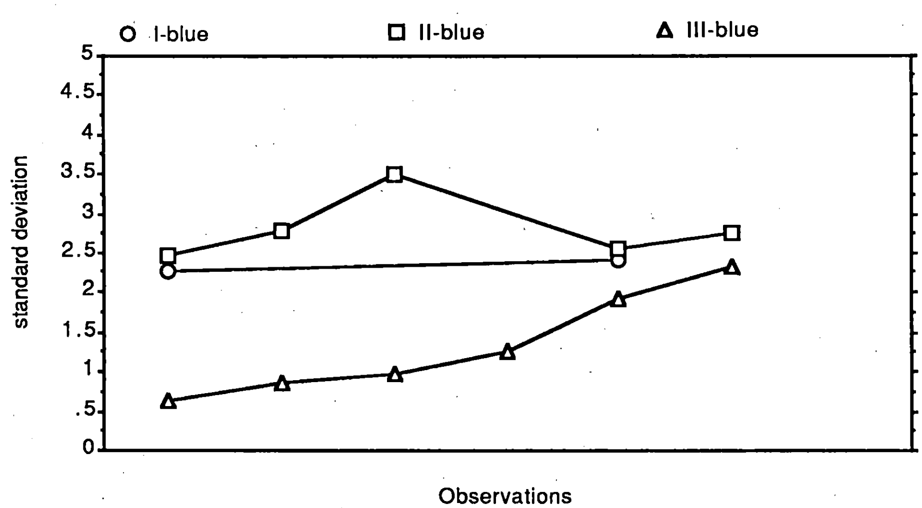


Figure 44. Comparison of pixel value standard deviations, between study phases

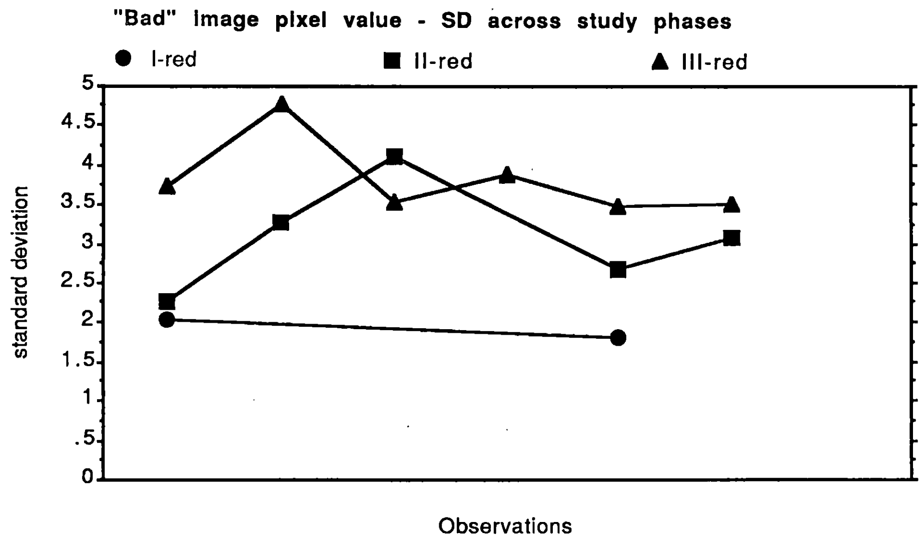


Figure 45. Comparison of pixel value standard deviations, between study phases "Bad" images, Red values

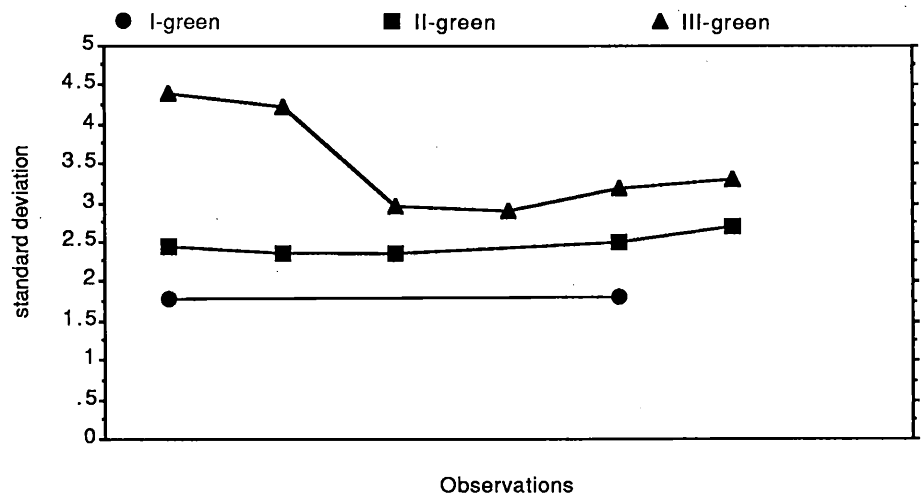


Figure 46. Comparison of pixel value standard deviations, between study phases "Bad" images, Green values

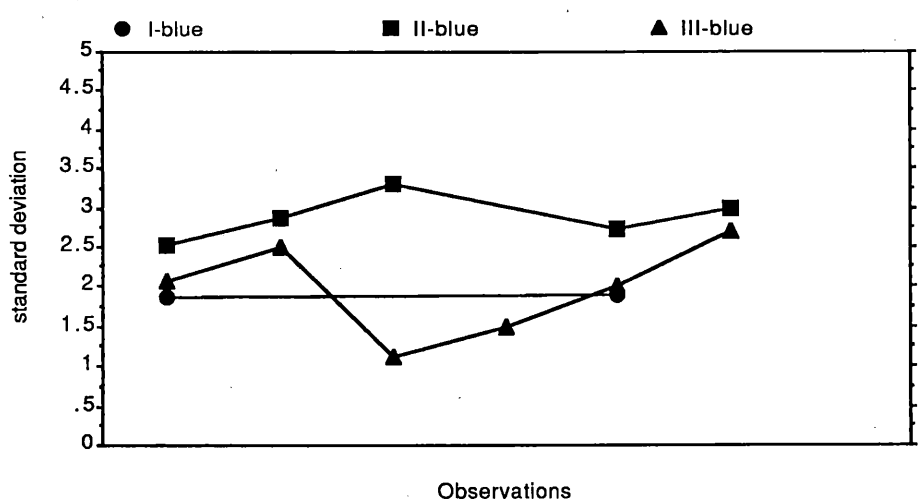


Figure 47. Comparison of pixel value standard deviations, between study phases "Bad" images, Blue values

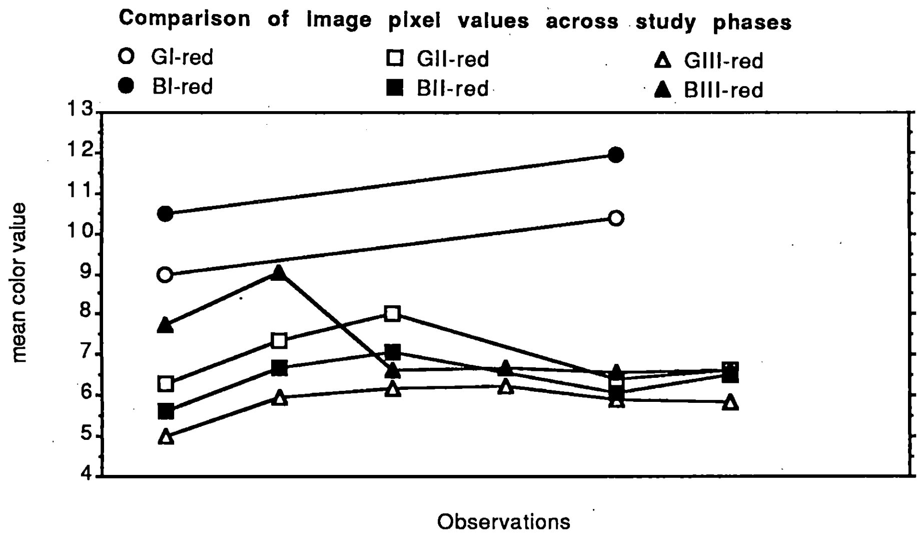


Figure 48. Comparison of pixel value between study phases "Good" and "Bad" images, Red values

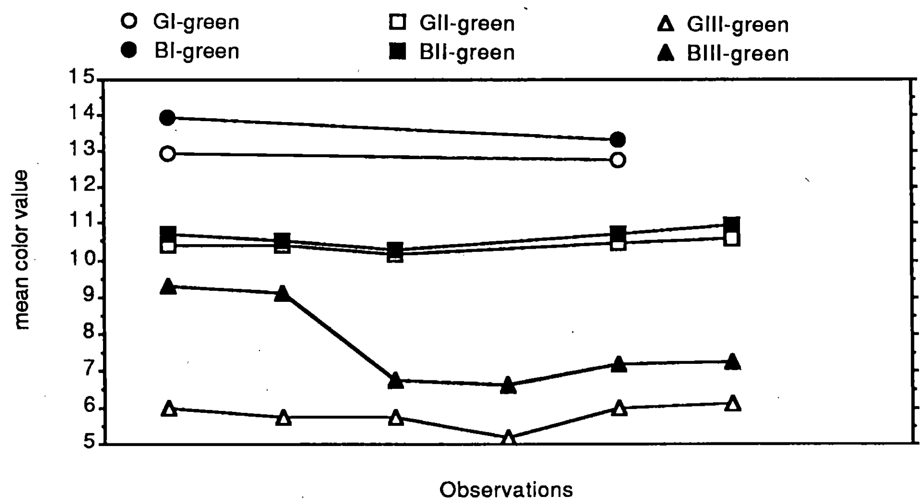


Figure 49. Comparison of pixel value between study phases "Good" and "Bad" images, Green values

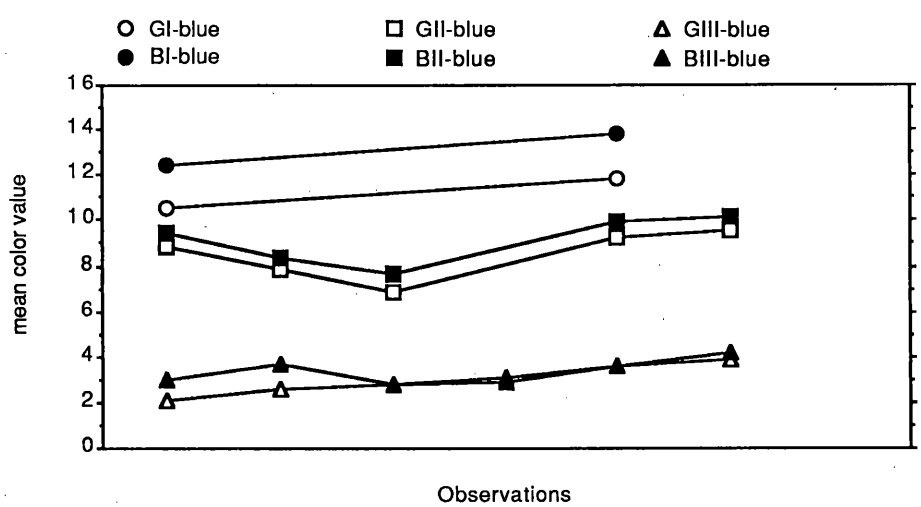


Figure 50. Comparison of pixel value between study phases "Good" and "Bad" images, Blue values

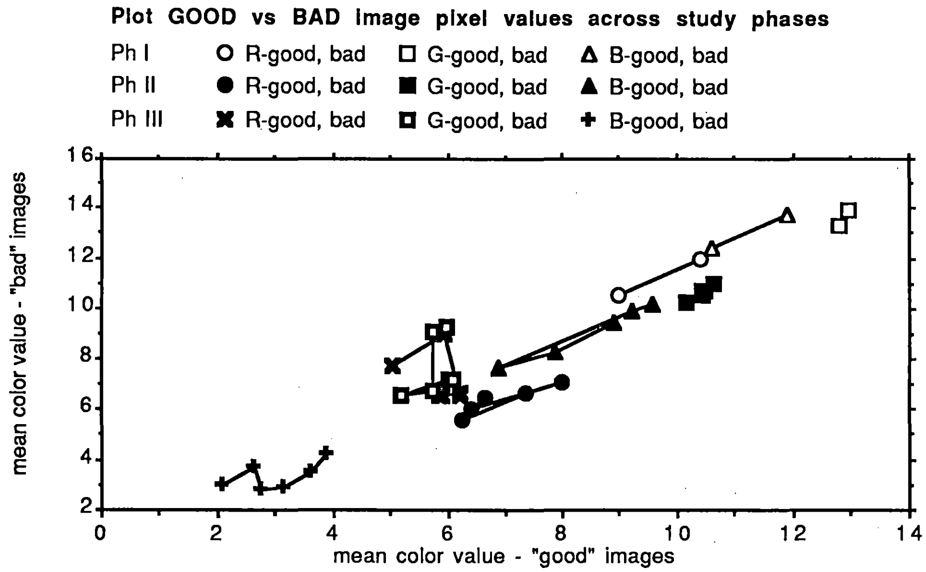


Figure 51. Plot Good vs Bad mean values for three phases
I - open symbols
II - closed symbols
III - line symbols